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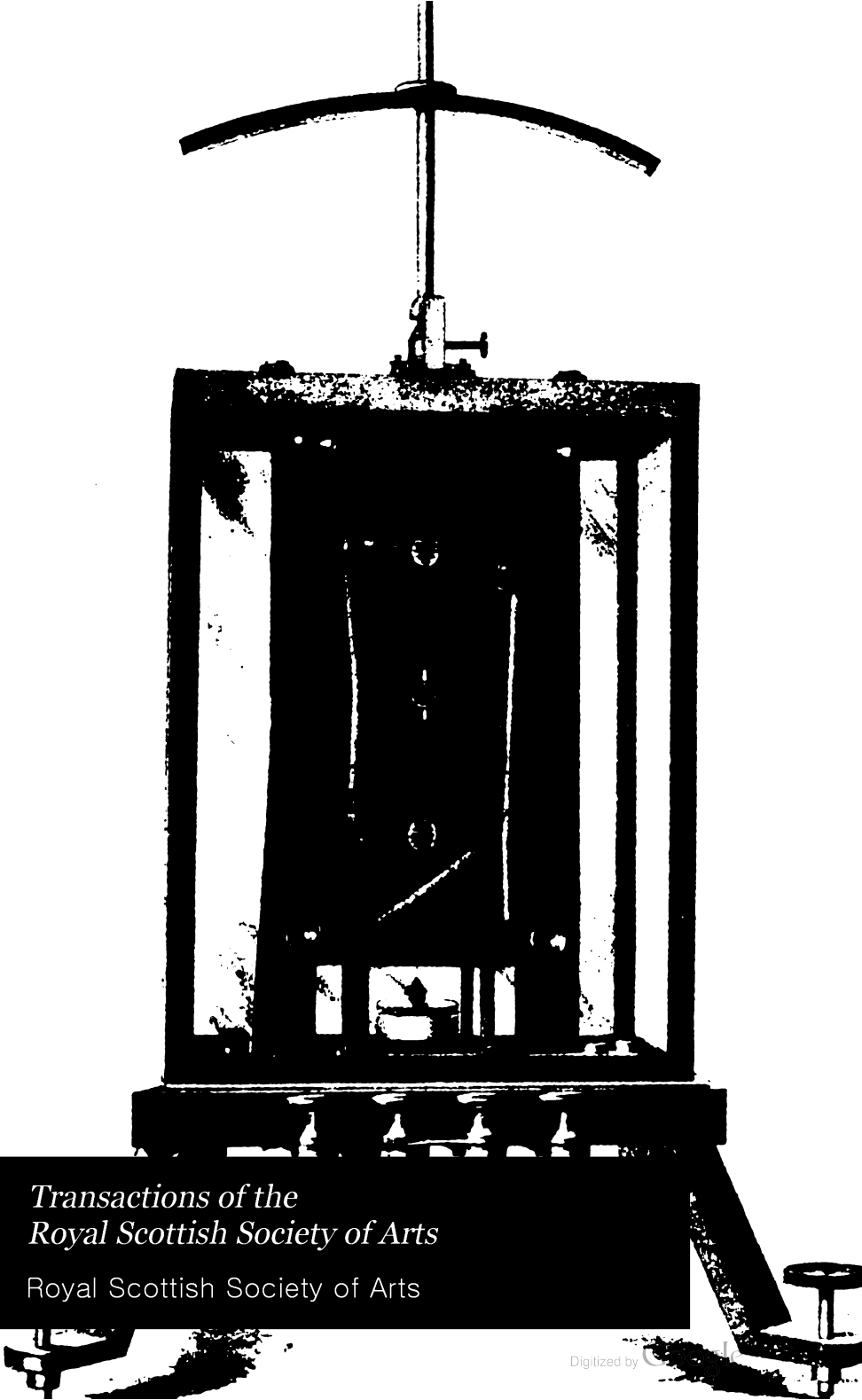

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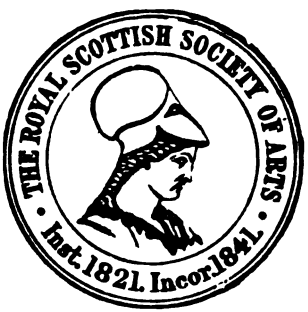

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TRANSACTIONS

OF THE

ROYAL SCOTTISH SOCIETY OF ARTS.

Notes on Method of Testing Steam Boilers, and Results of such a Test. By T. HUDSON BEARE, B.Sc., F.R.S.E., Assoc. M. Inst. C.E., Professor of Engineering and Mechanical Technology, University College, London. (With Plate.)*

THE author proposes to describe the method and results of a trial of the experimental boiler in his laboratory, University College, London. A boiler being simply a contrivance for converting the latent energy of the fuel burnt into the active energy of the steam produced, it is clear that the rational way of testing it is not merely to find out how many pounds of steam are generated per pound of fuel burnt, but to ascertain how many thermal units are given to the boiler by the fuel, and then to account for all these units. In other words, we have to make up a balance-sheet dealing with thermal units in place of pounds sterling, and as in the case of the money we always strive for a perfect balance so we should in that of the heat account. It would be poor comfort to a man who asked an accountant to balance his books to be told that of every £100 spent £75 was gone in trade expenses, but that the remaining £25 were unaccounted for. He would naturally desire a little more information, and would not rest till he had found out where the leak was. So, too, merely to say that a boiler evaporates 10 pounds of feed water per pound of coal burnt, when we know that the same coal burnt in a calorimeter evaporates 15 pounds, conveys but little information to the boiler-owner.

What are the two sides of our balance-sheet? On the one

* Read before the Society, 24th November 1890.

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side we have so many pounds of fuel burnt each hour, each pound containing a definite number of thermal units;* on the other side there are several items—so many pounds of feed water per hour heated and converted into steam using a known number of thermal units; so many pounds of furnace gases sent away each hour up the chimney containing a definite number of thermal units; so many thermal units lost in radiation; and, lastly, so many wasted in unburnt fuel, hot ashes, &c. There is nothing else, and if therefore we are to make up a satisfactory balance-sheet, observations must be made systematically on all these points. It is the author's intention to describe how this may be done, and what the results were in the trial in question.

It will be convenient first to describe the boiler which was tested. It was made by Messrs Lindsay Burnet of Govan, and is of the marine-loco type, having a wet bottom fire-box. The fire-box casing is semi-cylindrical on the top and bottom with flat sides, while the fire-box itself, which is 3 feet high and 3 feet broad, has a flat top. Behind the fire-box is a cylindrical shell 3 feet diameter containing 34 tubes opening into the smoke-box, from which an uptake leads away to the chimney. The grate area is 7·42 square feet; the heating surface, excluding the bottom of the fire-box, 205 square feet; the tubes being $3\frac{1}{4}$ inches diameter and 6 feet long between the tube plates, 174 square feet of this is tube surface; the external radiating surface, all covered with a thickness of about 2 inches of Keenan's non-conducting composition, is 143 square feet. Figures 1 to 4 show its construction clearly.†

Steam is supplied to a compound tandem engine, with 6 and 10-inch cylinders and 1-foot stroke. This engine was under test along with the boiler, but the results are not given in this paper. The boiler was steaming gently, and not developing anything like its full power. The trial therefore is not at all an economical one, and was not intended to be so, the main purpose being to afford the students working in the laboratory opportunities for taking part in such tests.

* Thermal unit = amount of heat required to raise 1 pound of water at 39° Fahr. through 1° Fahr.

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The trial was on May 11, 1890, and was nominally 5 hours in duration, beginning at 11 A.M. and finishing at 4 P.M. Probably the most difficult point in connection with a boiler trial is to decide in what manner to start and finish it. One plan is to wait till steam is up to the required pressure, then to draw all the fires and clean out the ashpit; the fires being relit with a weighed quantity of wood and shavings the trial begins, then at the finish the fires are again drawn and any unburnt fuel estimated. This plan has several disadvantages, notably the difficulty of preventing a big drop of pressure during the process of drawing and relighting, and also the uncertainty in estimating the amount of unburnt fuel at the end. Another method, and the one adopted in this case, is to get up steam to the working pressure, and have everything in ordinary running condition for some little time, then to cease stoking till the pressure begins distinctly to fall [say 5 or 10 pounds], stoking is then resumed from the weighed fuel, and this is taken as the starting time; in this case the pressure was 85 pounds when coaling was stopped, and it fell to 75 pounds before it was resumed, and the trial declared to have begun. A short time before it is desired to finish, stoking is stopped, and when the pressure has fallen to the same point as it stood at the start the trial is declared at an end. This does away with the necessity of estimating unburnt fuel. The fuel consumed during the trial is simply that put upon the fires during the time between the start and the finish, it being assumed, and apparently quite justifiably, that the fires and boiler contain as much heat at the end as they did at the beginning. The actual duration was 5 hours 3 minutes or 5·05 hours. The fuel was measured as follows:—100 pounds was placed in a box on a Pooley weighing machine (the box being counterbalanced), and after each stoking the contents of the box were weighed. We are thus able to tell not merely the total fuel used, but the rate of consumption (see fig. 7). As soon as the box was empty it was refilled with another 100 pounds.

The exact quantity of coal used was 216 pounds, and 10·4 pounds of ash were drawn from the ashpit. The coal was *Nixon's Navigation*. Samples were collected both for

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chemical analysis and for calorimetric determinations. The analysis was as follows:—

Moisture, ...	1·15 per cent.
Ash, ...	2·31 „
Carbon, ...	87·98 „
Hydrogen, ...	4·11 „
Oxygen, sulphur, &c. (by difference), .	4·45 „
	100·00

From this analysis the calorific value * of 1 pound of dry coal was calculated; the carolific values of carbon and hydrogen being taken as 14,544 and 62,032 thermal units respectively. It was further assumed that the whole of the hydrogen was available for combustion. In regard to this point it may be well to point out that the other plan of deducting from the hydrogen a part which is considered to be already combined with the oxygen in the fuel, and therefore useless for the purposes of combustion, always gives calorific values for coal much below those determined in a calorimeter.

The result of the calculation is 15,346 thermal units. This assumes that the steam produced by the combustion of the hydrogen falls to water; this is, of course, what happens in a calorimeter, but is physically impossible in a boiler furnace. Each pound of coal would give 0·37 of a pound of water.

In order to check these calculations, a calorimetric determination of the heat value of the coal should be made. The calorimeter used by the author is shown in fig. 5; it is on the principle of Professor William Thomson's, with a few modifications. A sample of the coal, chosen in such a way as to make it as representative as possible, is dried and well pounded; 2 grammes are then placed in the platinum crucible, A, and burnt by allowing a jet of pure oxygen under a slight pressure to impinge upon it. The crucible stands under a diving-bell, B, and this is immersed in a tall glass vessel, C, containing 2000 grammes of water, the whole instrument being surrounded by another glass vessel, D; the space between the two jars acts as an air-jacket, diminishing losses of heat during the experiment. The burning is carried out in the following way. The bell being drawn up above the water, the charged

* Calorific value of a fuel is the number of pounds of water at 39·4° F. which could be raised 1° F. in temperature by its perfect combustion.

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crucible is put in position, a small piece of fuse in it lighted, the bayonet joint securing the glass bell to its metal stand made, the whole lowered rapidly into the calorimeter, C, and the oxygen jet turned on. As combustion proceeds, the nozzle, E, by which the jet enters the bell, can be brought nearer to or further away from the crucible, thus perfectly controlling the rate of combustion. The products of combustion escape from the bell by holes in its base, and after circulating through short coils of brass pipe under this base, bubble up through the water and escape at the top of C, at the temperature of the water. For temperature observations two thermometers, both graduated to read to 0°·05 are used, one hangs inside the water in C, the other in the air close by; both are read at the beginning and end of the experiment. The water equivalent of C and its contents is easily found by weighing the separate parts, and reducing the values so obtained in the ratio of the specific heat* of water to that of the material of which the part is made; in this instrument they are equal to 110·4 grammes of water. As a result of our experiment we have a definite quantity (2110·4 grammes) of water raised in temperature a known number of degrees (due correction being made for radiation), and therefore have at once the calorific value of the fuel, it is—

$$\frac{\text{rise of temperature} \times \text{equivalent water-weight of calorimeter in grammes}}{2}$$

It must be remembered that the products of combustion fall in temperature to the water temperature. The radiation correction for the instrument can be easily determined by a series of observations of the rate of cooling of its contents with various air temperatures, and various differences of air and water temperatures; it is however very small, if care is taken to have the initial water temperature about as much below that of the air as the final is above it. The burning lasts about 20 minutes, and can be carried out by anyone used to careful work. The results are trustworthy to a high degree if care is taken in making the necessary weighings, temperature readings, &c., and in keeping the instrument in a

* Specific heat = number of units of heat required to raise 1 pound 1° F.

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room with a fairly constant temperature and protected from draughts.

The mean of five tests made with pure and dry samples of the coal gave 15,574 thermal units per pound of fuel. The amount of moisture present in the coal was determined on the day of trial by a careful drying test, and was found to be 1·50 per cent., the analysis made some days later shows a somewhat lower value.

Reducing the fuel consumption to the hour, we have—

$$\text{Actual coal used per hour, } \frac{2{\cdot}16}{5{\cdot}05} = 42{\cdot}77 \text{ pounds.}$$

$$\text{Total moisture present, } \frac{42{\cdot}77 \times 1{\cdot}5}{10{\cdot}0} = 0{\cdot}64 \text{ ,,}$$

$$\text{Pure and dry coal burnt per hour, } = 42{\cdot}13 \text{ ,,}$$

Hence, number of thermal units given to the boiler per hour was, working from the calorimeter observations—

$$42{\cdot}13 \times 15{,}574 = 656{,}133$$

We have thus the creditor side of our balance-sheet, and must now show how we can account for the expenditure of this heat, we will take the various items in order.

Steam Generation.—The feed for the boiler was drawn from a slate tank carefully graduated. Readings on the graduated scale, of the level of a float carrying a pointer, were taken every half hour during the trial. Thus not only was the total feed known, but also the rate of feed (see fig. 7). Behind the boiler gauge-glass was fixed a small scale engraved so as to show the number of pounds of water corresponding to any variation of level; this scale was graduated beforehand by actually weighing water into the boiler. Readings of this scale were taken every time the feed tank level was read. Corrections could thus be made so as to reduce the apparent to the real quantity of steam generated in each half hour. The temperature of the feed was measured each time its level was taken. The tank had to be refilled in the middle of the trial; the first tank full was 822 pounds, and its temperature (very constant) 71° F., and the second 608 pounds, with temperature 89° F.;

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the total feed being 1430 pounds, and its corrected mean temperature 78°·6.

The level of water in the boiler was accurately the same at the end as at the start. The mean steam pressure read every quarter of an hour was 79·3 pounds per square inch, and the barometer stood at 29·42", corresponding to an atmospheric pressure of 14·4 pounds per square inch. The absolute boiler pressure was therefore 93·7 pounds per square inch.

Just beyond the stop valve there is fixed on the steam pipe a separator for the purpose of catching and detaining any priming water. This was collected and amounted to 25 pounds during the trial, or about 1·7 per cent. of the total feed.

Reducing the above quantities to the hour as before, we have—

$$\text{Steam generated per hour, } \frac{1430-25}{5{\cdot}05} = 278{\cdot}21 \text{ pounds.}$$

$$\text{Priming water } \text{„} \quad \frac{25}{5{\cdot}05} = 4{\cdot}95 \text{ „}$$

Now each pound of steam evaporated, being fed in as water at 78°·6, and evaporated at a pressure of 93·7 pounds per square inch, *i.e.*, at a temperature of 323°·1 F., received in the boiler 1133·8 * thermal units, while each pound of priming water received 244·5 only.

We have, therefore, usefully spent

$$278{\cdot}21 \times 1133{\cdot}8 = 315{,}434$$
$$4{\cdot}95 \times 244{\cdot}5 = 1{,}210$$

or $316{,}644$ thermal units.

Equal to 48·2 per cent. of total heat.

The actual equivalent number of pounds of steam evaporated per hour correcting for the priming-water would be 279·3 pounds, and therefore the evaporation per pound of fuel is—

$$\text{Per pound of actual fuel, } \frac{279{\cdot}3}{42{\cdot}77} = 6{\cdot}53 \text{ pounds steam.}$$

$$\text{„ dry fuel, } \frac{279{\cdot}3}{42{\cdot}13} = 6{\cdot}63 \text{ „}$$

* *Vide* Northcott's Steam Tables.

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The factor of evaporation is $\frac{1133{\cdot}8}{966} = 1{\cdot}174$, and therefore the above reduced to the standard, from and at 212°, would be—

Per pound of actual fuel, $6{\cdot}53 \times 1{\cdot}174 = 7{\cdot}67$ pounds.
„ dry fuel, $6{\cdot}63 \times 1{\cdot}174 = 7{\cdot}78$ „

The rate of combustion is 5·76 pounds per square foot of surface of grate per hour, a very slow rate for such a type of boiler. The mean rate of transmission of heat through the boiler plates is $\frac{316{,}644}{205}$, or 1545 thermal units per square foot per hour as compared with about 3300 in a Cornish boiler, and 5600 in a marine one, again showing how gently the boiler was working.

Loss by Chimney.—The second item, viz., the loss by the heat carried away in the gases is very large in this case, because a large excess of air was purposely used. In order to determine it two sets of observations are needed, one the temperatures of boiler-house and flue gases, the other the collection at regular intervals of samples of the gases.

In regard to the temperatures, an ordinary thermometer is used to record that of the boiler-house, but for the flue a special instrument is needed. The one used, made by Müller of Bonn, is a long tube mercury thermometer, with the space above the mercury filled with compressed nitrogen. By this device it is possible to read temperatures much above the normal boiling-point of mercury. This thermometer was inserted into the uptake just above the smoke-box through a small hole carefully luted round with clay to prevent air leakage, and readings of it were made every 10 minutes. The mean temperature was found to be 453° Fahr., while that of the air in the boiler-house was 77° Fahr. Each cubic foot of air therefore in passing through the furnace was raised 376° Fahr.

The second point, the composition of the gases, was determined by drawing off samples in a bottle from the uptake, at about the same level at which the temperature was taken, and then volumetrically analysing these in simple fashion. Figure 6 shows the apparatus needed; the samples are

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collected in the bottles, A (which are half filled with a saturated solution of salt water), simply by displacement. Care must be taken each time to get rid of air in the pipe connections. The samples must be collected at regular time intervals, and the operation should be so slow that it occupies 15 or 20 minutes; then if such samples are drawn each hour a fairly representative collection will be obtained. As soon as each sample is collected it should be taken away and analysed at once, this prevents any danger of leakage or loss by absorption of the carbonic acid gas in the water. If continuous collection is made all through the trial a large vessel is needed, and if any accident occurs the whole experiment is spoilt, while by the other method only the one sample would be lost. The loss due to absorption of the CO_2 is also greatly minimised; this is why a saturated solution of salt water is used, the CO_2 being much less solvent in salt water. When the samples cannot be analysed at once it is far better to collect them in mercury bottles, the only drawback to its use being its weight and cost.

The analysis is made in the tall glass vessel, "the burette," B, which is graduated in cubic centimetres, the zero being a little way up from the bottom, which is constricted to a neck and closed by a cock. A similar neck at the top is also closed by a three-way cock while above this is an enlarged open cup, C. To start, the burette is entirely filled with salt water up to a marked point in the cup; gas from the collecting bottle is then allowed to pass into it by the three-way cock (all air in the india-rubber pipe connections being first bubbled away through the cup); the salt water escaping by the bottom cock till the burette contains exactly 100 c.c. The connection with the gas bottle being broken, the lower cock shut and the upper one opened to the cup, C, we have 100 c.c., of gas at a certain temperature and under a known pressure (measured by the depth of the water in the cup). The temperature must be kept unchanged throughout the experiment. The gases present are CO_2, N, O, and possibly CO; all these are tested for except the nitrogen, which is determined by difference.

The first gas tested for is CO_2, the top cock being closed, a slight vacuum inside the burette is produced by sucking out

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some of the salt water; a saturated solution of caustic potash (KHO) is then held under the lower cock and is forced up on opening it by the excess outside pressure; the contents are then vigorously shaken up, the burette being held in such a way that its contents are not heated by the hands, or the cocks disturbed. The CO_2 combines with the caustic potash. The burette is then replaced in its stand, and the top cock opened, the cup C being full, water runs in to take the place of the absorbed CO_2 and restores the pressure to its original value; the volume of the gases is found to be diminished, say it is now 93·7 c.c. then the percentage of CO_2 present was 6·3 per cent. An exactly similar series of operations is gone through to determine the oxygen, only the solution used is pyrogallic acid; care must be taken that the solution is alkaline, and very vigorous shaking up is needed to insure all the oxygen being absorbed. The pressure being again restored to the normal, the volume is read off, and the difference between this and the last reading gives the percentage of oxygen; thus, if it reads 80·2, then the percentage would be 13·5. The carbonic oxide * is tested for by a solution of cuprous chloride in hydrochloric acid, and requires great care and accuracy, since it is sure to be very small in quantity. Nearly all the water must be sucked out before the solution is used, as water precipitates the cuprous chloride, and after the operation is over all the contents must be thoroughly washed by allowing water to run through the instrument, removing any vapour of HCl present by a little KHO. The final remaining volume at the end of this is considered to be nitrogen only.

In the trial in question the composition as found, mean of four samples, was by volume—

Carbonic acid gas, . .	3·9 per cent.
Oxygen, ...	15·9 „
Nitrogen, ...	80·2 „

By a simple piece of calculation without any further measurements, we are able now to say very closely how many pounds of air passed into the furnace per pound of fuel burnt, and hence what was the loss of heat up the chimney.

* The author usually omits this test, as the percentage of CO, if present, is under normal conditions so small that it cannot be relied on.

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The first step is to convert the above volume percentages into weight percentages, this is done below.

By Weight.

$3{\cdot}9 \times 22 = 85{\cdot}8$ therefore $CO_2 = \frac{85{\cdot}8}{1463} = 5{\cdot}86$ per cent.

$15{\cdot}9 \times 16 = 254{\cdot}4$ „ $O = \frac{254{\cdot}4}{1463} = 17{\cdot}39$ „

$80{\cdot}2 \times 14 = \frac{1122{\cdot}8}{1463{\cdot}0}$ „ $N = \frac{1122{\cdot}8}{1463} = 76{\cdot}75$ „

Now, practically, all the carbon present must have come from the fuel, and all the nitrogen from the air; each pound of CO_2 has $\frac{3}{11}$th of a pound of C, therefore each pound of furnace gas has $\frac{5{\cdot}86}{100} \times \frac{3}{11} = 0{\cdot}016$ pound of C and 0·7675 pound of nitrogen. Each pound of pure carbon burnt must have drawn into the furnace $\frac{0{\cdot}7675}{0{\cdot}016} = 48{\cdot}0$ pounds of nitrogen, but in the air the proportion by weight of N is $\frac{77}{100}$; and, therefore, each pound of pure C burnt, received $48 \times \frac{100}{77} =$ 62·4 pounds of air. From the analysis, we know that each pound of fuel had 0·88 pound of carbon; so finally, the air sent into the furnace per pound of fuel was $62{\cdot}4 \times 0{\cdot}88 = 54{\cdot}9$ pounds.

That is, for each pound of coal burnt we may say we have 56 pounds of furnace gases, each pound raised 376° in temperature.

The specific heats of the constituents being known it is easy to calculate approximately that of the mixture, viz.:—

$5{\cdot}86 \times {\cdot}217 = 1{\cdot}271$
$17{\cdot}39 \times {\cdot}218 = 3{\cdot}791$ *i.e.*, mean sp. heat is 0·238.
$76{\cdot}75 \times {\cdot}244 = 18{\cdot}720$
$23{\cdot}782$

The heat rejected in the dry furnace gases per hour is therefore $376 \times 42{\cdot}77 \times 0{\cdot}238 \times 56 = 214{,}334$ thermal units. It has not been thought worth while to make a correction for unburnt fuel in ashes.

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During each hour there was also formed and sent away up the chimney as steam $42{\cdot}77 \times 0{\cdot}37 = 15{\cdot}8$ pounds. Each pound carries away the sensible and latent heat from 77° to 212°, and also the heat of superheating the steam up to 453° F.,

$$\begin{aligned} 15{\cdot}8 \times 1101 \quad &= 17396 \\ 14{\cdot}8 \times 241 \times {\cdot}48 &= \underline{1828} \\ &\quad 19224 \text{ thermal units.} \end{aligned}$$

The total loss up the chimney is therefore 233,558 thermal units or 35·6 per cent.

Radiation.—To ascertain at all accurately the extent of this loss is a somewhat difficult and uncertain operation. One way in which it can be done is to get up steam to the desired pressure, then draw all the fires and ashes, close stop-valve, fire door, and damper, and observe at regular intervals the pressure of steam and temperature of boiler house, till the pressure inside the boiler falls to atmospheric pressure. From these observations, and the known weight of the boiler and water in it, it is possible to deduce fairly well the rate and amount of loss in thermal units when the pressure is steady and boiler working. Another method, and the one adopted in this case, is, as soon as pressure has been got up to the required point, to draw all the fires except a very little, shut stop-valve, nearly close the damper, and then keep on adding to the small fire left just sufficient coal to keep the steam pressure steady. If this is done for some hours a very good approximation to the actual radiation can be got; for since the pressure and temperature of the boiler and its contents remain constant, all the heat supplied by the combustion of the coal used must go in radiation and in losses by chimney gases.

A few days after the main trial a test of this character was made. Its duration was 4¼ hours, the boiler pressure being kept almost constant at 77 pounds per square inch. The total amount of coal used was 39·4 pounds or

$$\frac{39{\cdot}4}{4{\cdot}25} = 9{\cdot}27 \text{ pounds per hour;}$$

reduced to pure and dry coal this is 9·13 pounds.

An attempt was made to ascertain how much of the heat of this fuel went up the chimney, but the volume of air was

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necessarily so great per pound of coal burnt, and the combustion so irregular, that the analysis of the gases could not be relied upon to give a fair sample of the average; perhaps if the greater part of the fire bar air spaces had been closed up a more accurate result might have been obtained. The results were therefore discarded, and it has been assumed that, since on the main trial 36 per cent. of the total heat went up the chimney, at least 50 per cent. would be lost in this manner with such a large volume of air passing through the furnace; this gives

Loss by radiation in thermal units per hour

$$9{\cdot}13 \times 15574 \times 0{\cdot}5 = 71095.$$

or 10·8 per cent.

This corresponds to $\frac{71095}{174} = 408$ thermal units per square foot of surface exposure per hour, while a series of experiments on the same boiler, three years ago, carried out in the other way, gave the mean loss by radiation at this pressure as 330 thermal units per square foot per hour, so that the above values are reasonably correct.

The other possible forms of loss are (*a*) those due to imperfect combustion, which is tested for in determining the CO (if any), present in gases, (*b*) that due to evaporation of moisture in fuel, (*c*) unburnt fuel in ashes.

(*a*) It was quite certain, from the large excess of air, that there would be no loss under this head. As a proof no CO was found in the analysis. If any be present, the calculation of the loss due to it is easily made, for we know that for every pound of carbon burnt to carbonic oxide only, a definite number (10,093) of thermal units are lost.

(*b*) Is a small item easily allowed for. In each pound of coal there is 1·5 per cent. or 0·015 pound of water. This water is evaporated and carries away up the chimney all the latent heat of evaporation, as well as the heat spent in raising the steam formed up to the temperature of the chimney gases.

Water evaporated per hour is $42{\cdot}77 \times 0{\cdot}015 = 0{\cdot}64$ pound.

Heat spent in raising from 77° (air temperature) to 212° and evaporating water is $0{\cdot}64 \times 1101 = 705$ thermal units.

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Heat spent in raising this steam to 453° (temp. chimney) is $0{\cdot}64 \times (453 - 212) \times 0{\cdot}48 = 74$ thermal units.

Total loss is therefore = 779 thermal units.

(*c*) The total ash drawn from the ashpit per hour was $\frac{10{\cdot}4}{5{\cdot}05} = 2{\cdot}06$ pounds, but the percentage of ash in the fuel as determined by analysis was 2·31 per cent; and, therefore, the 42·77 pounds burnt per hour should have produced only $42{\cdot}77 \times \frac{2{\cdot}31}{100} = 0{\cdot}99$ pounds; the unburnt fuel in ashes was, therefore, $2{\cdot}06 - 0{\cdot}99$ or 1·07 pounds per hour, the heat lost was therefore $1{\cdot}07 \times 15{,}574 = 16{,}664$ thermal units.

We are now in a position to make up our balance-sheet, and see what balance we have unaccounted for; this is given below (see figure 8).

Cr.	T.U.	*Dr.*	T.U.	Per cent.
By 42·13 lbs. of pure and dry coal burnt per hour,	656,133	To steam evaporated,	315,434	48·1
		To priming water, .	1,210	0·2
		To heating waste gases, &c., . .	233,558	35·6
		To radiation, . .	371,095	10·8
		To loss in ash, . .	16,664	2·5
		To evaporation moisture, . . .	779	0·1
			638,740	97·3
		Balance unaccounted for, . . .	17,393	2·7
	656,133		656,133	100·0

The balance is very close considering the difficulties of the task were rendered much greater than they would ordinarily be by the necessity of working the boiler so gently and uneconomically.

The author's object will have been obtained if he has made it clear how easy it is to make a thorough test of a boiler, and to find out where there are heat leaks, and how they can be stopped. None of the apparatus needed is expensive, except perhaps a good calorimeter, the cost of the one used in this trial was about £16; the cheaper, Thomson's, will give quite good results if only a proper empirical correction is used with them. Full descriptions of calorimeters will be found in a paper by Messrs Donkin and Holliday, in *Proceed-*

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ings of Institution of Civil Engineers, vol. cii., and of gas analysis in two recent numbers of *Engineering*, October 3 and 10, 1890.

How important it is for a manufacturer or millowner to know whether his boiler plant is really working efficiently, needs, the author feels, no argument. Coal costs money, and money saved in daily working expenses in these days of close competition often means the difference between profit or loss. It is, moreover, a duty every user of coal ought to take to heart —to lessen the waste of this precious commodity—seeing at what an alarming rate our supplies are being used up. Curves on figure 7 show rates of fuel consumption, water evaporation, gas temperatures, &c.

Notes on the Early History of the Steam-Engine and Steam Navigation. By Wm. Allan Carter, C.E.*

During the session 1888–89, when Mr Salvesen submitted his communication to the Society as to the question of Symington's right to be recognised as the inventor who had brought the question of Steam Navigation to a successful and practical issue, I made a half promise to the Society to bring forward some Notes on the Early History of the Steam-Engine, but always hesitated to do so while I had more important and original communications to place on the billets. Having, however, been disappointed with two papers for this evening, I find myself forced to step into the breach, and trust you will accept the urgency of the situation as an excuse for any shortcomings in the fare I am able to provide.

Many of you may be aware that an effort has been made to provide a suitable memorial in Edinburgh to Symington, and I acted as local secretary to the committee. During the time we were collecting funds, I was frequently struck with the complete ignorance displayed as to the history and development of the steam-engine, even amongst engineers. By the present generation, the steam-engine is simply accepted as a

* Read before the Society on 8th December 1890.

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fact; but, with regard to its past history, Watt and the steam-engine, Bell and the "Comet," seemed to sum up the whole of the general information floating about; and the popular idea is that Watt invented steam, and Bell invented the steamboat. It may, therefore, not be unprofitable, and, I trust, not uninteresting, to recapitulate some of the incidents which have marked the advance of the utilisation of steam in the steam-engine.

It is sometimes stated that the knowledge of steam, and even of its use as a motive power, was acquired long before the Christian era, and in many works written on the subject, Hero of Alexandria, who lived about 130 B.C., obtains the credit of having first invented a steam-engine. There is no doubt Hero was a philosopher, and wonderfully advanced for the times in which he lived; but, although he produced a piece of mechanism in which motion was induced by steam, he himself was ignorant of the fact, and knew nothing whatever regarding the properties of steam or the vapour of water. The mechanism on which Hero's credit rests is now sometimes seen in the form of a toy known as the Æolipile, or ball of Æolus. It consists of a little pot or boiler filled with water, from which a tube is carried to a ball free to revolve on an axis. The ball is furnished with two curved outlets at opposite sides, so that when steam is generated in the boiler and admitted to the interior of the tube, it finds an escape by the curved outlets, and the reaction of the steam against the atmosphere causes the ball to revolve. We have no reason to believe that Hero regarded this otherwise than as a toy or amusing physical experiment, and it is only in drawing on our imagination that we may come to fancy the classical philosopher as already hatching the idea of the steam-engine. It would be a mere waste of time to recount the sayings and writings of the wise men of that era, for, although great interest attaches to them, there is such a vagueness of language employed that no practical result can be arrived at, and it is more to our purpose to advance to a later period, when the history of men and their works becomes more reliable and lucid.

Leaving Hero, therefore, who flourished about 130 B.C.,

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I make a sudden jump of more than thirteen hundred years, when I think it worth while to rest a moment to mention the name of Roger Bacon, not that he developed the idea of the steam-engine, but because some of the opinions he expressed seem in the present day to be almost prophetic. Bacon was born at Ilchester, in Somersetshire, in the year 1214. He received his education at Oxford, and afterwards went to Paris, where he continued his studies and took a theological degree. The physical sciences had great attractions for him, and, notwithstanding the difficulties put in his way by fanatical religious brethren, he continued to study them earnestly; and it is related of him that, to satisfy his craving for knowledge, he laboured to acquire a command of Latin, Greek, Hebrew, and Arabic in order to read in the original language such scientific works as were then obtainable. He thus acquired as great a knowledge as then existed of mathematics, astronomy, physics, and chemistry, and gathered around him the young men of his order, by whom he was known as the "Admirable Doctor." He studied the subject of lenses, and actually made spectacles for the use of the aged brethren; he enunciated the theory of the telescope, a theory which only bore fruit about 400 years afterwards, when the great Galileo had brought his genius to bear on it. The manufacture of gunpowder attracted his attention, and he seemed to foresee the wonderful power with which it was vested, for he writes that—"it is sufficient to ignite a very small quantity of this substance to produce much light, accompanied by a horrible noise. By this means a town or a whole army may be destroyed." In his great work, *The Opus Major*, we find the following most significant lines:—"We will be able to construct machines which will propel large ships with greater speed than a whole garrison of rowers, and which will only need one pilot to direct them; we will be able to propel carriages with incredible speed without the assistance of any animal, and we will be able to make machines which, by means of wings, will enable us to fly in the air like birds." Compare the large ship propelled by a machine with a modern steamship! the carriage travelling with incredible speed without the assistance of any

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animal with the modern railway train, and the machine with wings to soar in the air like a bird with a modern balloon, and we cannot help being impressed with the wonderful manner in which these words of Bacon have been verified. At the same time, we must admit that Bacon had no notion of how these wonders were to be brought about, and his predictions are most probably due to the fact that he appreciated the ignorance which surrounded him, and foresaw that that ignorance would sooner or later give way under the repeated assaults of an ever-developing human intellect, and that, as ignorance gave way, wonderful things such as he suggested would probably result. It is a pleasant thing to imagine the brilliant light of genius shining out in the midst of darkness whole centuries in advance of all its surroundings; but we require to be very cautious not to attribute too much to such eccentricities of genius, as by so doing we are apt to wander from the paths of truth, and lose ourselves in a mere imaginary sentimentalism.

When we consider the immense value of the steam-engine to the civilised nations of the world, it is not unnatural that there should be a certain rivalry as to who shall be credited with the invention. In England, Savery, to whom I will allude to at greater length immediately, invented a steam-engine in 1697, and claimed for himself the credit of being the original inventor; this claim was resisted by Denis Papin, a Frenchman. Papin, however, was a Protestant and a heretic, so his countryman, the Abbé John de Hautefeuille, not wishing the credit of such an invention to be allowed to any one outside the pale of the Church, contested Papin's claims, and desired to have the credit to himself. It was then that the English people entered into the dispute, and claimed priority for the Marquis of Worcester, on the strength of his having published his century of inventions in 1663. Our French neighbours then went a little further back, and endeavoured to instal their countryman, Salomon de Caus, as the great original inventor, he having written a work in 1615 on the "Properties of Moving Forces." Salomon de Caus was an ingenious engineer and architect, who did much good work in his day, but whose opinions were simply those of his own day.

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He had no conception of what steam was; his knowledge was very little in advance of that of Hero, and the great engine on which his renown was based consisted of a spherical boiler (fig. 1), which had to be filled with water, and having a tube reaching almost to the bottom. When fire was applied to the boiler, the pressure of steam on the upper surface of the water forced the water up the tube to form a little fountain. But Salomon de Caus himself was not aware of the action of the steam, and in fact could not distinguish between steam and heated air, the latter being the term then employed for steam, just as in the days of Hero. In recent times it has been the popular belief that Salomon de Caus died a raving lunatic, and as a good instance of how a popular error may be spread, I relate how this belief came to be held. In 1834, Henry Berthaud, one of the editors of a French paper, was publishing in his paper a romance in which one of the characters was a madman, and he instructed Gavarni, the engraver, to supply an engraving of a raving madman in his cell. The engraving, however, was not executed in time, and the story had to be published without it. Some time afterwards the engraver, having finished his task, sent the picture-block to Berthaud, to whom it was now useless. But, as he considered it a silly thing to possess an engraving and not make use of it, he drew up a fictitious letter, purporting to have been written by Marion Delorm, the mistress of the Marquis of Worcester, in which it was stated that the Marquis and herself, in visiting the prison of Bicêtre, had seen Salomon de Caus confined behind strong bars, shouting out—"I am not mad! I have made a discovery which will change the whole world!" and the engraving was published to illustrate the letter. Artists, authors, dramatists, without taking trouble to verify this history, have made poor Salomon de Caus the subject for their pen and pencil, depicting him in all the terrors of lunacy, whereas he died quietly in Paris in the full possession of all his senses, and holding the appointment of engineer to Louis XIII. When Berthaud confessed, in 1847, the part he had played in this little fiction, he had some difficulty in making the public believe him. They much preferred Salomon de Caus as the lunatic.

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If Salomon de Caus' claim to be the inventor of the steam-engine is a poor one, that of the Marquis of Worcester is still more unsatisfactory. The Marquis, who lived in the time of Charles I., was a royalist, and during the Commonwealth was imprisoned in the Tower, where, no doubt, he had plenty of leisure for quiet meditation. After the Restoration, he published his great work, "A Century of the Names and Scantlings of such Inventions as at present I can call to mind to have tried and perfected, which, my former notes being lost, I have, at the instance of a powerful friend, endeavoured now, in the year 1655, to set down in such a way as may sufficiently instruct me to put any of them in practice."

It is quite possible that the instructions may have been sufficient for the Marquis himself, but no one else since his time has been able to make anything of them. Watt tried his hand at them, but found them too obscure to be of any value. The sixty-eighth invention described is certainly a means of raising water by the aid of fire, but the description is so confused that engineers have failed to design a pump which could at all correspond with the Marquis's invention.

I have already mentioned the name of Savery, whose claim we may now consider. Thomas Savery, an Englishman, born in Devonshire about the year 1650, was, without doubt, the first who invented and constructed a steam-engine which possessed any practical value; and, although it may be denied that the conception was original, he undoubtedly had that peculiar faculty which enabled him to grasp the theory and apply it in practice. He was a well-educated man, and began life as a military engineer, but he does not seem to have remained long in the service. Savery's youth was spent in the neighbourhood of a great mining district in Devonshire and Cornwall; but up to this date the mines were worked more like our quarries in the hill-sides, as miners had no means of keeping deep mines free from water. Of course, the quantity of ore which could be got in this way was limited, and, in order that the industry might continue, pumps became a necessity, and, as you all know, necessity is the mother of invention. Savery, who had invented various machines, amongst which was one for polishing plate-glass,

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and another for propelling a boat by means of a paddle-wheel, had his attention now called to the want of the miners, namely, a good pump, and finally came to the conclusion that steam was the agent to be employed. There are generally some little interesting anecdotes concerning great discoveries which, although frequently having no foundation in fact, nevertheless lend a certain charm to their history, and demand our indulgence. It is related that Savery, having dined one day at a country inn, and having finished his bottle of wine, threw it amongst the embers of the fire, then, calling for a basin of water, was preparing to wash his hands when he noticed that the remnant of wine left in the bottle had disappeared, having been converted into vapour. Putting on his glove to save his hand from being burnt, he lifted the bottle and thrust it, mouth downwards, in the basin of water, more in idle curiosity than anything else, to see what effect that would have. In a minute he saw the water in the basin rush upwards, and fill his bottle. The steam having become condensed, a vacuum was formed in the bottle, and the pressure of the atmosphere forced the water from the basin to fill the void. Thus, Savery acquired a knowledge of the behaviour of water in presence of a vacuum caused by the condensation of vapour, and this principle he applied to his engine. But, as Boyle and Papin had before this made many experiments on steam, the results of which were known in England, some doubt has been expressed as to the truth of this little experiment in the wayside inn. Be that as it may, Savery, after years of labour, struggling with all sorts of difficulties, constructed an engine (fig. 2), which actually worked. It was essentially a pump, and nothing but a pump, and the principle on which it worked was this: There was a boiler in which steam was generated, and from which it was conducted to two chambers alternately by different pipes, each having a stopcock. These chambers were connected with the suction pipe at their lower ends, and also with the delivery-pipe clack-valves, having an upward motion being fitted to them. Above the chambers was a tank of cold water furnished with a movable nozzle, by means of which cold water could be poured over each of them. Now you will easily see the

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action: we open one of the steam-cocks, steam rushes into the chamber, and displaces the air; then the nozzle is turned over it, and cold water is poured over it, the enclosed steam becomes condensed, a vacuum is created, and water rushes up the suction pipe and fills the chamber. In the meantime, the same process has been going on with the other chamber. The steam is now again turned on to the first chamber, and by pressure forces the water up the delivery-pipe, leaving the chamber full of steam, which is again condensed, and so on, each chamber acting alternately.

Savery erected several of these engines in Cornwall, but he had difficulty in getting them introduced; and as they were liable to explosion from the imperfect workmanship then available, and the great pressure of steam required, his engines were gradually superseded by those of Newcomen, a native of Dartmouth, and a blacksmith by trade. Newcomen was not altogether an uneducated man, but had certainly not received any scientific training, so that, although some have endeavoured to credit him with original inventive genius, it is more likely that he was aware of what Savery had done, and only improved on Savery's engine; and from a correspondence which took place between him and Robert Hook, a member of the Royal Society, it would appear that he (Newcomen) was also aware of what Papin had already done in the same direction. The engine now introduced was very different from Savery's. It consisted of a boiler (fig. 3), over which was placed a cylinder, in which was fitted a piston capable of working up and down. The end of the piston was connected with an oscillating beam by means of a chain, and from the other end of the beam a chain was connected to the plunger rod of a pump. A tank of cold water was provided, and this water was thrown by a pipe on the outside of the cylinder to condense the steam. The action was as follows:—Suppose the piston, to begin with, at the bottom of the cylinder. The steam-cock on the boiler is opened, and the pressure of the steam, together with the counter-weight of the plunger, caused the piston to rise to the top of the cylinder, leaving the pump-plunger at the bottom of its stroke. The steam-cock is now shut off, and the cold water turned on. The steam in the cylinder is condensed,

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and the pressure of the atmosphere forces the piston down into the cylinder, at the same time drawing up the plunger. So, by simply turning two cocks, this up and down motion is communicated to the machine. It will be noticed that the steam is not used here directly as the motive power. The power is got from atmospheric pressure, the use of the steam being merely to produce a vacuum under the piston. An engine such as this was erected at Wolverhampton for the first time, but its action was miserably slow. We can imagine the anxiety of the inventor seeing his machine labouring slowly up and down, and saying to himself, "if I could only get this affair to work quickly—if I could whip more life into it—how valuable it would be." Anxiously regarding it, he is astonished to see it suddenly make two or three quick strokes, and then fall back into its lazy habit. What was the meaning of the little acceleration? It was this: In order to prevent steam passing between the sides of the cylinder and the piston, some water was kept lying on the top of the piston. A little hole having been knocked through the piston, this water trickled through, and caused rapid condensation of the steam, producing a correspondingly rapid descent of the piston. Newcomen saw this, and immediately altered his engine so as to make the cold water be injected into the inside of the cylinder instead of only playing on the outside, and, thanks to this new arrangement, the piston was now able to make eight strokes a minute. This was about as fast as the boy in attendance could turn the two cocks. The engine was not yet automatic. A man or boy had to be constantly turning the steam and water cocks. If he stopped, if he got lazy, the engine got equally lazy. Can we imagine a more wearisome occupation than to sit all day turning two handles, now on, now off, eight times each minute. A boy, whose name is now famous, was engaged in this interesting, if not exciting, occupation at Wolverhampton—Humphrey Potter—of whom the following story is told. He was a smart boy, but an idle one, and it grieved him deeply that he could not get away from this wearisome occupation for a single minute without his absence being known. He saw his companions stealing half an hour from their work to have a

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game or a ramble, but he could not join them for one minute without the engine stopping and telling tales on him. There is no doubt it was a wretched situation for him to be in, when a happy idea struck him. He saw the great beam working up and down. If he tied a string to the handle of the cock and fixed it to the beam, as it ascended it would pull the cock open. Another string might in the same way be made to shut it. So he worked away with his strings until he got the beam to open and shut both cocks at the right moments, and then off he darted to have a right good scamper on his own account. So this idle but ingenious little vagabond converted the engine into an automatic machine, and whereas he had only been able to make it work eight strokes per minute when turning the cocks with his hand, he now made it work itself, at a rate of fifteen or sixteen strokes, by means of a few ingeniously arranged strings. It is quite possible that the character of the boy has been maligned, and that very different motives instigated his actions, but it is needless to say that the idea was at once taken advantage of, and a mechanic of the name of Brighton shortly afterwards substituted an iron frame, worked by the beam, which opened and shut the cocks automatically. Newcomen's engine received little or no alteration until it came into the hands of James Watt. Up to this time the condensation of the steam within the cylinder had been obtained either by the application of cold water to the outside of the cylinder, or by the injection of cold water within the cylinder. The effect of this was to reduce the temperature of the walls of the cylinder at each stroke, and a large quantity of steam was lost in again raising the temperature. Watt appreciated this defect, and arranged that the condensation should take place in a separate chamber. By this modification an economy of 50 per cent. was at once realised, but up to this period the machine was not in the proper sense a steam-engine—that is to say, power was not obtained through the elastic expansion of the steam, but only through an arrangement of condensing steam on one side of a piston, forming a vacuum, and so allowing the pressure of the atmosphere acting on the other to force it down, the upward motion being obtained by the counter-balancing of the beam.

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Watt, however, after his successful arrangement of the separate condenser, took up this other question, and designed his cylinder so that expanding steam should act on one side of his piston, helping the vacuum on the other, and thus produced the veritable condensing steam-engine. So far, however, the engine had only been used as a pump. Watt's perspicacity enabled him to see that a much wider field was open to the steam-engine, if the continuity of its action could only be maintained, just as the revolutions of a water-wheel were continuous. To effect this he arranged for the steam to be delivered alternately on each side of the piston, and now the cumbrous balance-weights of Newcomen could be dispensed with, the piston under the influence of expanding steam against a vacuum travelling in both directions of its stroke with the same power. Of course, now the connection between the piston-rod and the beam required to be made of rigid parts, instead of the flexible chains used by Newcomen, which were only subjected to a pulling stress. Now the stress was alternately tensional and compressive, and rigidity became essential. Watt's first idea was to make a toothed wheel at the end of the beam work on a rack fixed to the piston-rod, but the noise and clumsiness of the arrangement at once condemned it, and in 1784 he designed the beautiful parallel motion, which, no doubt, all of us have admired over and over again, when watching the oscillations of the beam of the old-fashioned beam-engine. The next step was the conversion of the up and down oscillations of the beam into a rotatory motion by the use of the crank on the driving-shaft; and, lastly, we find him designing successfully the ball-governor, by which an automatic regulation of the speed became possible.

We see, therefore, through these successive modifications, the tremendous strides made by the steam-engine in the hands of Watt; and, having got thus far, it would be quite beyond the scope of this paper to follow the development of the engine further—a task for which I am quite unfitted. I will therefore retrace my steps, and seek rather to traverse the question of the application of this motive power to the propulsion of vessels on water. The credit of being the first

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to apply the steam-engine to navigation has been eagerly sought after, and disputed not only on individual but also on national lines.

Some historians have endeavoured to give Spain the credit, and have brought forward the name of Blasco de Garay as the illustrious inventor. The history of his invention, and of himself, rests on the authenticity of a single manuscript, from which it would appear that a public trial of a steamboat was made at Barcelona in the year 1543 before a Royal Commission. Garay did not divulge the secret of his machine, nothing being known of it except that it consisted of a boiler containing boiling water, and wheels, which propelled the ship. The Commission reported that no greater speed than 2½ miles per hour could be obtained, and that the machine was too complicated, too costly, and too much subject to explosions. Under this very adverse criticism, Garay dismantled his engine, and nothing more was ever heard of it. It is extremely unlikely that any such experience as this took place, for at that date no machine had been constructed which would work itself, much less supply motive power, if we except the Æolipile already mentioned, a modification of which was employed in Leipsic fifty years later to turn a roasting-jack; and it is difficult to believe that if a boat had been constructed to travel at 2½ miles an hour by means of a steam-engine in 1543, the knowledge of it should have been so completely lost and so barren of all practical results, and that fifty years later the only known use of steam should be to turn a kitchen utensil. But, although we may entertain doubts as to Garay's boat, we have no right to pass his name in silence.

We must now turn to the history of a man who was much better known, and whose genius and misfortunes entitle him to our respect and sympathy. Denis Papin, a Frenchman, born at Blois in the year 1647, was intended by his parents to follow the medical profession, and having studied medicine, obtained his doctor's degree from the University of Orleans. Such, however, was his love for natural science that he gave up entirely the practice of his profession, and devoted himself to the study of physical science and mechanics. He was

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encouraged in so doing by Huygens, the great Dutch astronomer, then resident in Paris, and a leading member of the Academy of Science. Huygens supported Papin and supplied the necessary funds, and in return Papin assisted him in perfecting his instruments and otherwise experimenting. Papin had at this time most promising prospects, the scientific men of Paris held him in the greatest esteem, and everywhere he was received with favour. Suddenly, however, without any known cause, Papin left Paris and came to London, and shortly after his arrival presented himself to Robert Boyle, one of the most eminent men of his day. The result of their meeting was that Boyle received Papin into his laboratory, and for three years they worked together, investigating various problems in physical science. During this time Papin was admitted as a member of the Royal Society of London through the influence of Boyle, who was the illustrious founder; and it was before this Society that Papin first exhibited his wonderful digester (fig. 4), which was simply a strong stew-pan with a cover capable of being screwed down, so that when water was introduced into it, and the lid closed and heat applied, the steam, instead of escaping, was confined and gained pressure. Papin was aware that steam under pressure was hotter than steam at atmospheric pressure, and he endeavoured to take advantage of this in order to cook meat and other viands quicker than in an open pan, and also to reduce bones and cartilage to gelatine. But a difficulty met him; he could not see into his pan, and was therefore ignorant of how his stew was getting on, and, as he says himself, "I sometimes drew the meat out before it was cooked, at other times I had it burned, as I had no means of knowing the amount of pressure or the degree of heat." To meet this difficulty, Papin invented what is now known as the safety-valve. He formed a hole in the lid of his pan and fitted a valve over it, with a lever and weight, and could calculate what pressure would lift the valve, and with the pressure could calculate the heat. Papin had no intention in the first instance that this valve should serve as a safeguard to prevent excessive pressure, his only notion then being that he could from it form some idea of the state of matters within

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his pan and not risk an underdone or overcooked dinner. It was only after a lapse of twenty-seven years that it occurred to him to apply this valve to boilers connected with engines as a means of safety from explosion.

Papin's prospects in England were now very promising. With Boyle for his friend his scientific career was almost assured, when overtures were made to him from a new Academy of Sciences then being formed in Venice, and these, as Papin says, were made with a liberality and generosity altogether extraordinary. Papin, with the unfortunate restlessness which characterised him through life, accepted the chair offered him and left London. For the next two years we find him working in Venice and making a great name for himself, but the extraordinary liberality and generosity seem to have been confined to the overtures, and that money was not so plentiful in the City of the Doges as promises. Papin, therefore, seeing himself growing daily poorer and poorer in the substantial good things of this world, left Venice and returned to London. But his friends were now not so hearty as formerly, and he had some difficulty in getting on. However, the Royal Society appointed him its curator at a salary of £2, 12s. per month, and on this Papin continued to struggle for some time, until, in fact, in 1687 Charles, Elector of Hesse, offered him the Chair of Mathematics in the University of Marburg. He accepted this post, and the Royal Society, to testify their appreciation of his services, presented him with four volumes of the *History of Fishes*. Four sovereigns would have been much more acceptable to poor Papin; however, he accepted the presentation and departed, and soon afterwards was installed in his mathematical chair in Marburg. Up to the present time his ideas on a moving machine to supply power were extremely vague and undefined. The efforts he had made experimentally were quite unsuccessful. He had now, however, more time to give to the consideration of the subject, and we find him turning over in his mind all sorts of expedients. His ruling idea was to produce a vacuum below a piston, and so utilise the atmospheric pressure; the difficulty was how to obtain this vacuum. He had tried to obtain it by water power, and had

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failed; he now tried to obtain it by means of gunpowder. The idea was not original; it had been previously suggested by the Abbé de Hautefeuille, who designed a machine to pump water from the Seine to feed the fountains at Versailles. The Abbé's pump consisted of a cylinder, or case, situated 30 feet above the level of the water to be lifted, and furnished with four valves. When a charge of gunpowder was exploded in this case, the air was expanded and escaped by the valves: thus a partial vacuum was produced, and the water raised to a certain height above its normal level. Huygens, Papin's first friend, had also experimented with a gunpowder machine, so that Papin had the benefit of their experience. He found, however, that a perfect vacuum could not be obtained in this way, and eventually he abandoned the idea, but, in doing so, conceived the idea of forming a vacuum by the aid of steam. In following up this idea, he took a cylinder and fitted a piston into it, the cylinder being closed at the bottom and open at the top. In the bottom of the cylinder he put a little water, and then brought the piston down until it touched the water. He then applied heat to the cylinder—in fact, put a fire under it. Steam was generated, and the piston rose. Heat having generated the steam—this elastic vapour—Papin judged that cold would destroy it, and as the putting of the fire below his cylinder had caused the upward motion of the piston, the withdrawal of the fire would produce the reverse effect, and the piston would fall.

Papin's first steam-engine, therefore, was to work by means of bringing his fire alternately under his cylinder and taking it away—a terribly clumsy idea. He calculated his piston could be made to work at the rate of one stroke per minute, but by having a series of cylinders, and moving the fire from one to the other, he could obtain continuous motion. He published a minute account of this invention in 1690, under the title of *A New Method of obtaining considerable Force at little Cost*, and after detailing his arrangement of construction, he goes on to mention the manner in which it could be applied, and, with a naiveté which is charming, says:—"How are we to employ this force to draw

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water from mines, shoot bullets to great distances, to navigate vessels against the wind, and many other applications? It would take us too long to examine, but everyone can devise an arrangement of the machine to suit his own purpose. I will say, however, in passing, that in many ways a force such as this would be preferable to the employment of oarsmen for the propulsion of vessels." We have here, then, a clear expression of opinion as to the advantage to be derived from the application of the steam-engine to navigation.

But let us push on and see how Papin fared in trying to apply his invention in a practical way. He met with no encouragement from anybody, adverse criticism encountered him at every step, and at last Papin, completely discouraged, began to think he really was altogether on the wrong track, and abandoned his idea. Fifteen years passed without any advance, when Leibnitz, travelling in England, saw one of Savery's engines at work, and sent a description of it, with a drawing, to Papin, who submitted it to the Elector, and was instructed by him to construct such an engine. This was a retrograde movement on the part of Papin. He abandoned the grand idea of a piston raised by steam and thrust down by atmospheric pressure—the condensing steam-engine, in fact—and reverted to a very vicious type of pump, with which he proposed to pump up water and, by allowing it to fall on a water wheel, procure power which he could apply in various ways. He ceased to be original, and became a mere imitator of Savery. However, he now proceeded to build a boat on the river Fulda, and provided it with an engine on this principle—working paddle-wheels.

Misfortune, however, seemed ever to hang over his head, and when he appeared just on the point of success fickle fortune failed him. He had made some powerful enemies in Marburg, and his position had evidently become uncomfortable there, for in a letter which he writes to Leibnitz in 1707, he desires to return to London. His letter is as follows:—

"Sir,—You know that for long I have complained of having many and powerful enemies. I have regarded them with patience, but lately I have experienced their animosity in such a way that it would be foolhardy for me to remain here longer exposed to such dangers.

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"I am sure that I would obtain justice were I to go to law, but I have already caused his Highness to lose too much time with my little affairs, and it is better to retire and quit the place than to be obliged too often to importune so great a prince. I have therefore presented a petition, humbly praying him to accord me permission to retire to England, and his Highness has consented in terms which cause me to see that he is still kinder to me than I deserve.

"One of the reasons I alleged in my petition was, that it is important for me to test my boat at a seaport such as London, where one can bring every test to bear on this new invention, which, by means of fire, will render the work of one or two men of more effect than several hundred of rowers. In fact, my intention is to make the voyage in this very boat of which I have already had the honour to speak to you, and from which larger and more convenient boats may be modelled. But there is a difficulty, viz., that no boats run from Cassel to Bremen direct, for, when merchandise arrives at Munden, it has to be discharged and transferred to other boats which descend to Bremen. I have been assured by a boatman of Munden that I will require express permission to effect a passage with my boat from the Fulda and down the Wesser.

"This determined me, sir, to take the liberty of applying to you, as this is an entirely personal matter. I am sure you will have the kindness to procure me the necessary permission for the passage of my boat to Munden, seeing that you have already expressed your views, and the value you put on this fire-machine as a means of navigation."

Leibnitz endeavoured to obtain this permission from the Elector of Hanover, but failed; or at least there was such delay that it was tantamount to a failure. Papin, however, was continuing his experiments with his boat, improving his machine, and getting, according to his own idea, good work out of it, for shortly afterwards, again writing to Leibnitz, he says:—

"The experiments I have made with my boat have succeeded beyond my hopes, and the force of the current is so insignificant compared with the power of my machine, that I have difficulty in knowing whether I am going with the current or against it."

He accordingly builds great hopes of success on exhibiting his boat in London, but the permission to travel never came, and he begins to lose heart, saying:—

"I see myself in great danger after so much trouble and expense laid out on this boat of having to abandon it, and so deprive the public of the advantages which I would have been able, God aiding me, to procure by its means. I console myself, however, in the fact that it is not my fault, for I could never have imagined that an invention such as this should come to grief for want of a pass."

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Failing then to obtain the permission of the Elector of Hanover, Papin takes the bold determination to pass down the rivers without it, and on the 25th September 1707, he embarked on board his boat with his family and all his worldly possessions, and began his voyage down the stream. What mingled emotions must have occupied his mind at this moment, pride and confidence in his boat, shadowed, however, with dark distrust of his fellowmen. No contrary incident occurred until he reached the junction of the two rivers, where the jurisdiction of the boatmen came into force. The appearance of Papin's strange boat at once attracted their attention; actuated by curiosity and jealousy, considering, no doubt, that this machine, by dispensing with the necessity for boatmen, would ruin them. Held in check by their president, they for some time attempted no violence, but the president, named Zeuner, being a timid and cautious man, and not wishing to embroil himself with his fraternity, retired from the scene, leaving Papin in the hands of an ignorant crowd. This rabble then informed him that, as he had attempted to travel without permission, his boat and all his goods were forfeited, and then giving way to that ungovernable fury into which a crowd can so easily work itself, utterly regardless of reason or justice: these men fell upon Papin's boat with hatchets and crowbars, or whatever implement first came to hand, and ruthlessly demolished it. Let us picture to ourselves the despair which must have seized Papin at this moment. He had worked thoughtfully, patiently for years, and the outcome of it all was this miserable scene in which the brute force of ignorance seemed to triumph. Papin was now sixty years old, he was past the age when men rally from a serious disaster; the blow to him was fatal so far as his success in life was concerned, he had no longer heart or hope or means to commence anew: he had thought over this engine for a whole lifetime, he had worked out its details, and had manufactured it pipe by pipe and wheel by wheel, he had fitted it together at a time when skilled mechanical labour was not obtainable, and what was the result? So far as he was concerned, absolute failure, not through the acknowledged imperfection of his mechanism, but through the viciousness of ignorance. He

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now found himself in terrible straits, he was absolutely penniless, and scarcely knew where to turn to find friends. He had led such an unsettled life, had thrown up so many posts, that his friends were disappointed with him. He could not think of returning to Marbourg, France was closed against him on account of his religious views, England only seemed open to him, and to England he again returned, but no longer as the brilliant and successful scientific man; now he only appears as a broken-down disappointed old man, thankful to obtain a small pension from the Royal Society. Little is known of his declining years, or the exact date of his death, but he seems to have dragged out the remainder of his life in poverty and misery. There can be little doubt, giving due consideration to the times in which he lived, that Papin was a man of considerable genius and ability. He was the author of many original ideas which have since proved of great practical value, but he himself seems to have lacked the faculty of turning his ideas to advantage, or of following up the logical sequences of his own conceptions. In designing his digester he clearly invented the safety-valve, but not for the purpose of a safe-guard. To us the idea of its being utilised as a safe-guard on steam-boilers is so obvious that we can scarcely understand how Papin failed to grasp the idea for so many years.

Following Papin, a number of inventors sprang up, but for long very little progress was made. In 1724, an Englishman named Dickens took out a patent for a steam-engine, to be used for the elevation of water and the propulsion of boats, but with no practical result. In 1737, Jonathan Hulls, another Englishman, adapted the Newcomen engine to the propulsion of boats, and transformed the linear motion of the piston into a rotary motion, causing paddle-wheels to revolve.

In 1753, the Abbé Gauthier presented a memoir to the Academy of Sciences of Paris, in which the whole question of steam, the steam-engine, and navigation are treated in a wonderfully shrewd manner. In his day ships were either propelled by sails or by a large number of oarsmen, as in the galleys; and those who were interested in the steam-engine naturally compared its work with that performed by a gang

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of oarsmen in a galley. He calculates that such a boat, with twenty-six oars on each side, and manned by 260 men, could attain a speed of about five miles an hour, and that it would be necessary to have two such squads, the one to relieve the other. The Abbé then brings forward the objections which were raised to the steam-engine—its bulk, the quantity of coal required, and the danger of fire. To which he replies that the engine will not take up so much room as the 500 men, that the fuel will not occupy so much space as the nourishment of the said men, and as to fire, that is a mere matter of judicious arrangement. The Abbé, however, confined himself to theoretical arguments, and did not put them into practice.

Then we have a Swiss named Genevois, who published a pamphlet in London in 1760, entitled *Some Discoveries for the Improvement of Navigation.* His notion was to have an apparatus at the side of the boat like a duck's foot, contracting and expanding in the water, as no doubt you have all seen when it makes its stroke. He also got hold of the gunpowder idea, and thought a serviceable machine might be worked with it, and mentions that a Scotchman had succeeded thirty years previously in propelling a ship with such a machine 7½ miles, with an expenditure of thirty barrels of gunpowder, which, I think, showed that the scientific Scotchman was not to be deterred by trifles.

The next decided effort to put these theories into practice was made by two French noblemen—the Count Joseph d'Auxiron and the Chevalier Charles Monnin de Follenai. They formed a little company, and built a boat on the Seine, and on January 1773 the engine and boiler were erected on board. The attention of the boatmen on the Seine had been attracted to the undertaking, and they regarded it with a somewhat menacing eye. In order to ensure the safety of the boat, it was moved from l'Ile des Cygnes to Meudon, and was carefully watched until its completion, about September 1774, when suddenly one evening it was sunk in the middle of the river. It is thought that one of the principal workmen had been bought over by the river boatmen, and that he purposely allowed the enormous counterpoise of the piston to

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fall into the bottom of the boat, causing a serious leak, through which she foundered. This broke up the company, and in short caused the death of the inventor, for Joseph d'Auxiron, only forty-seven years of age, had an attack of apoplexy, to which he succumbed. But at this moment another French nobleman, the Marquis de Jouffroy, came on the stage. The Marquis, as a young soldier, had fought a duel with the colonel of his regiment, and in order to give him time to reflect in coolness on the enormity of such a transaction, he was imprisoned on the island of Sainte Marguerite for a period of two years. While there, his principal occupation was watching the galleys being rowed by convicts, and his reflections naturally turned in the direction of some machine which might supersede this animal labour. No sooner liberated, then, than he came to Paris, and, meeting Follenai, endeavoured with his aid to start another company, amongst whom were Jacques Perier, a skilled mechanic, and the Marquis Ducrest. A meeting was held in the rooms of the latter, but at the very outset a difference of opinion cropped up between Perier and Jouffroy as to the power of the engine required; and as they could not reconcile their opinions, the company broke into two camps, Perier working with his friends, Jouffroy leaving Paris altogether. Perier constructed a vessel, and engined it according to his calculation, but it turned out a complete failure, so we can dismiss him and turn to Jouffroy, and see what he made of it. According to a French writer, he established himself on the banks of the river Doubs, a tributary of the Seine, constructed a boat, and put an engine of Watt's into it. He constructed an apparatus at each side on the duck's foot principle, and this little boat sailed on the Doubs for a couple of months, but it did not satisfy its inventor, for he soon abandoned it, and, going to Lyons, commenced a larger boat on the paddle-wheel principle. This boat was about 140 feet long by 16 feet beam, and the engine was a most ambitious affair, the cylinder being 21 inches diameter and 5 feet long, while the paddle-wheels were 14 feet in diameter. The success of this boat was, in the opinion of all who saw it, quite complete. On the 15th July 1783, in presence of thousands of spectators and of the members of the Academy of Lyons, the boat

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travelled up the Soane, and Jouffroy got gratifying assurances from the influential men of the town of their satisfaction. It has been asked how could such a success remain barren of good fruit. One would naturally think that steam navigation having got this length would have steadily developed, and become recognised as a means of locomotion; but, incredible as it may appear, long years were yet to pass ere steam navigation was considered by the public as even practicable. Jouffroy's boat had been built of too light timbers to give it the necessary strength for everyday work, so he proposed immediately to construct a stronger vessel, and form a company to work a regular steam service on the Soane. It was necessary, however, before doing so to obtain exclusive privileges to manufacture and use such boats, and he accordingly petitioned Government, and sent the testimonials and certificates he had obtained guaranteeing the success of his boat at Lyons. The minister (Calonne), however, to whom the petition was addressed, did not accept these proofs as final, but consulted the Academy of Science, and the members of the Academy, flushed with the dignity of their position, thought it necessary that there should be a trial made of the boat under their own eyes at Paris, and appointed a Commission to examine and report on the whole matter, consisting of Brissot, Cousin, and Perrier, the latter being Jouffroy's rival, with whom he had quarrelled, who had himself experimented on steam navigation and failed. Jouffroy, knowing the men he had to deal with, saw that his efforts were hopeless, and he abandoned them. Soon afterwards, entering the army of Conde, he gave himself up to military service, and many years passed before he had another opportunity. It was not, in fact, until the year 1816 that Jouffroy succeeded in launching a steamboat on the Seine, and by that time other countries had made great strides in the question of steam navigation.

I must now ask you to take a jump from France into Scotland, and see what was being done at home. A shipbuilder named Patrick Miller, aided by James Taylor, who occupied the position of tutor in his family, designed an engine and paddles to propel a boat, and having employed a skilled mechanic, William Symington, constructed their engine, and

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put it to trial on a sheet of water situated at Dalswinton. The boat worked wonderfully well, running at the rate of five miles an hour, and so encouraged the inventors that they determined to construct a large boat, and gave an order to Boulton and Watt, who were at this time carrying on business as engineers at the Carron Works, for a large engine. The paddle-wheels were to be worked by an endless chain running over pulleys. On the completion of the boat she was tried on the Forth and Clyde Canal, but on the first trial the blades of the paddles broke, and then the endless chain broke, and, in short, the whole mechanism failed. Miller, disgusted at his failure, abandoned steam navigation, and sent the engine back to Boulton and Watt to be taken to pieces. This experience was made in the year 1789. The idea, however, had taken root in the mind of Symington, and when the Scotch mind gets hold of an idea it generally holds on to it with remarkable pertinacity, turns it over and over, and ends by making something out of it; so it is not surprising that ten or twelve years later Symington succeeded in constructing a very satisfactory steamboat.

Between 1801 and 1803 Symington, under the auspices of Lord Dundas, recommenced his studies and efforts to produce a practical steamboat. The result was the launching of the "Charlotte Dundas," which, in March 1802, made its successful trip on the Forth and Clyde Canal with the "Active" and "Phœnix" in tow. The difficulties of the engine having been fairly overcome, Symington anticipated every success; but the proprietors of the canal, fearing that the wash from the paddles would injure the banks, put a veto on the boat so far as the canal traffic was concerned. The unfortunate death of the Duke of Bridgewater was another serious blow to Symington's chances of success, for the Duke had ordered Symington to construct eight boats similar to the "Charlotte Dundas" for use on his own canal, but the order was scarcely secured when the Duke died, and his successors declined to go any further in the matter. Success, which had seemed almost within his grasp—for there was no doubt as to the going qualities of the "Charlotte Dundas"—now seemed like a Will-of-the-wisp, to recede and evade the hand stretched out to seize it and

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Symington's last years were spent in comparative poverty, supported by his friends. He received a donation of £150 as a royal grant, but the country which was to benefit so enormously by steam navigation did not think fit to recognise him in any way. Thanks to the energy of a small knot of his countrymen, a monument has been raised to his memory in the district where he was born, and the memorial bust by our townsman, D. W. Stevenson, R.S.A., has a prominent position in the Museum of Science and Art.

Before passing from Symington to other workers, it is necessary to mention that amongst many who visited him on board the "Charlotte Dundas" was Fulton, the founder of steam navigation in America, and who, on that occasion (July 1801), was shown the whole of Symington's arrangements, and enjoyed a trip on the canal. I shall refer again at greater length to Fulton's career, on which this visit to Symington had a very marked influence.

In order to follow the history of our subject, I have now to carry you over to America. In 1783, the Act of Independence having passed, peace reigned again on the great Continent, and American citizens were turning their minds to the development of all kinds of industries. The knowledge of Watt's engine had reached America, and two men came forward almost simultaneously with projects for its adaptation to navigation—John Fitch and James Rumsey. Fitch was ready with his trial boat first, and during the summer of 1787 made a public trial of it. His boat was a grotesque-looking affair, having the engine in the centre and six large upright oars or paddles on each side. These were worked by a kind of frame, so that when three were in the water making their stroke the other three were out on the return stroke. Notwithstanding the clumsiness of the arrangement, the boat worked well, and it was calculated that it attained a speed of five miles an hour on dead water—that is, without current. This trial excited very great interest in America, being the first of its kind. Both Franklin and Washington were on board, as well as other influential men, who all congratulated him on the success he had obtained.

A company was at once formed to carry out the scheme on

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a large scale, and amongst the promoters were Franklin and Rittenhouse, both names of great scientific interest. Accordingly in 1788 the Government of the United States granted this company the sole privilege of building and working steamers for fourteen years. The trial boat was, however, a very small one, and Fitch now experienced the same difficulty which had crushed so many inventors. What worked well in a small model was almost hopeless when attempted on a large scale. The expense of construction was immense, and the result most disappointing. Still Fitch worked on, and succeeded at last in getting his new boat to run at eight miles an hour; this was a wonderful success, and Fitch seemed on the high road to fortune. But public favour is a fickle mistress. Many of Fitch's friends became afraid of the expense of manufacture of such boats. Rumsey was also attracting attention, so that Fitch found himself left gradually out in the cold, without friends and without popularity. He was quite satisfied himself as to the future of steam navigation, and one day, talking to one of his workmen, he said:—"I am too old to see it, but you will see the day when steamboats will navigate the Atlantic, and create between the old and the new worlds easy and quick relationship." The result of this remark was, that he was considered absolutely mad, the man remarking, "What a pity that such an excellent man should be so cracked." Nevertheless, in less than fifty years from the date of this remark, steam-vessels were plying between England and America, and, in fact, only twenty-seven years later, the first steam-vessel effected a passage from America to England.

The French Consul resident at Philadelphia, Crèvecœur, had taken a lively interest in Fitch, and seeing the value of steam navigation, recommended him to go to France, and, armed with introduction, Fitch sailed for France in 1792, and this country, which had given no encouragement to Papin, d'Auxiron, or Jouffroy, was now offered the invention of the steam-boat once more by an American.

Thanks to the influence of Crèvecœur, Fitch was well received, and explained his invention to the National Convention. Brissot de Warville backed him up, and a gleam of

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sunshine seemed to be breaking once more in his career. But these were troublous times in France. On the 31st October 1793 Brissot perished on the scaffold. Fitch found himself friendless in a country convulsed with revolution, he had to beg from the United States Consul the money to convey him back to his own country. Continued reverses had now preyed deeply on his mind, he saw nothing round him but gross ignorance and inconstancy, he gave himself up to a bitter melancholy, and sought consolation from sources which could only intensify his misery. One evening, walking on the cliffs which border the river Delaware, he looked down on the scene of his labours, where visions of success had gladdened his earlier years, and where one after another his hopes had foundered. Utterly worn-out and dejected, sick of life which had brought him no satisfaction, reproaching his fellow-men who had supported him only to desert and abandon him in the hour of need—in a moment of despair he plunged from the cliff into the dark waters, whose current he had endeavoured to stem, and which now, closing over his head, swept him out to the vast sea of eternity.

James Rumsey, who had started at the same time as Fitch, was disappointed in not obtaining some privileges from his Government, and accordingly thinking there was a better field for him in England, left his own country and established himself with us. His ideas as to the method of propelling a boat took quite a different turn from those of his predecessors. His notion was to pump in water at the bow of the boat and force it out at the stern, the reaction causing the boat to advance. The idea was not original, but he has the credit of putting it into action, and in 1793 his boat, so constructed, travelled against wind and tide at a speed of 4 miles an hour, a somewhat loose statement, and which we may accept with considerable reservation. Rumsey does not seem to have developed his invention, and the main reason for his name being mentioned is because he directed the attention of Robert Fulton to this great question, and for having merely done that he merits recognition.

Robert Fulton was born at Little Britain, in Pennsylvania, in 1765, his parents being poor emigrants from Ireland. He

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received the ordinary education of a village boy, and was afterwards apprenticed to a jeweller in Philadelphia. His talent, however, did not lie in this line, drawing and painting occupying all his spare hours, and so hard did he work in this way that at the age of seventeen he added considerably to his income by the sale of his pictures. Finally, he gave up all notion of becoming a jeweller, and commenced travelling from village to village, painting and selling his pictures. After gaining a certain practice in this way, he established himself as a miniature painter in Philadelphia, but, soon afterwards, being advised to come to London where his talent would have more scope, he did so, and became a pupil of Benjamin West. He had not yet, however, hit on the profession most suited to his tastes, for he soon gave up high art and devoted himself to the study of mechanical draughtsmanship, and we next find him occupying the post of draughtsman in an engineering shop in Birmingham. In 1788 he returned to London and met Rumsey, and then had the question of steam navigation brought under his notice. Fulton at once appreciated the importance of the question, and the value which a successful solution of the problem would be to his country, with its great sea-board and its immense navigable rivers and lakes.

While the friends were only in the midway stage of discussing the merits of the various systems, Rumsey died, and Fulton was left to be guided by his own judgment. For eight years he does not seem to have advanced far, although he brought out a number of other inventions, but receiving little encouragement he left England and went over to France. At this time, 1796, the English navy held a command of the seas, and during our wars with France our navy dealt many heavy blows at her commerce, from which other nations also suffered, and especially America; and Fulton, notwithstanding his residence in England, seemed now to have but one idea, namely, to invent a boat which might damage the English ships. He set himself to work to devise a submarine boat; in fact, he conceived the idea—which has since received such development—of torpedo warfare. He made out plans and specifications of his boat, and addressed it to the French

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Directory, but his scheme being judged impracticable, his petition for assistance was dismissed. He next made a model of his boat, and again addressed himself to the Directory. He was now better received, and a Commission was appointed to investigate his plans. Considerable delay occurred, as is not unusual where Commissions are concerned; and, finally, Fulton was informed that his scheme was definitely rejected. He had occupied himself some years with this scheme, and on its rejection found himself penniless. In order to fill his purse, he took to his brush once more and painted a panorama, which he exhibited in Paris. All Paris went to see it. It was a complete success, and Fulton found himself quite set up again, and able once more to continue his labours on submarine warfare.

Bonaparte had now been appointed life Consul, and Fulton addressed himself to him. Bonaparte entertained the idea of his scheme, and another Commission was appointed to examine his plans, and provide funds for his assistance. Fulton now constructed a large torpedo-boat, and in 1801 made a trial of it at Brest. He submerged himself, says a French writer, in the boat to a depth of 40 fathoms, remained twenty minutes under water, and then came to the surface, after having travelled a considerable distance under water. He then plunged again, and returned under water to his starting point. It is stated that on the 17th August 1801 he remained four hours under water, and travelled in that time 12½ miles. An old sloop was put at his disposal. He started his torpedo-boat 200 yards from it, and in quarter of an hour blew it into pieces. He then kept a look-out for English cruisers; and it is stated that on one occasion he was just on the point of reaching a 74-gun ship, when by luck the man-of-war changed her course, and so Fulton missed his mark. Bonaparte now began to get tired and impatient, gave little attention to the memoirs and addresses of Fulton, and finally the inventor was informed that the French Government would give him no further assistance. Finding himself again abandoned, he determined to return to America, when his good fortune introduced him to Livingston, his countryman, a diplomatist, who was then in France transacting the business connected

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with the treaty ceding the State of Louisiania. Livingston had made himself acquainted with all that had been done in the way of steamboat construction, and had demanded a monopoly from his own Government to use steamboats on the waters under its jurisdiction. This had been promised to him on condition that he within a year produced a boat commanding a speed of three miles an hour. He dissuaded Fulton from returning to America, and entered into an engagement with him to supply the funds, Fulton supplying his skill and experience. After great labour and many checks, Fulton at last built a boat, constructed his engines, and fitted them on board, and a trial was to be made on the Seine at Paris, when one morning he was rudely awakened by one of his workmen, who brought him the news that his boat had broken into two pieces, and engine and all had sunk in the middle of the river. Here was a repetition of the accident which had been the deathblow to Le Comte d'Auxiron twenty-five years previously. Fulton's first feelings were those of despair; but being a man of strong determination, he put himself in action at once, and it is related that for twenty-four hours he worked with his men, without a moment's rest and without a bite of food, but succeeded in dragging his engine from the bottom of the river. It became necessary, however, to build a stronger boat to receive his engine, and this was accordingly done, and in August 1803 the boat was working before the eyes of the people of Paris. The trials being so far successful, Fulton demanded from the First Consul an examination of his boat and an expression of opinion from the Academy of Sciences, offering, if that was favourable, to dedicate his labours to France; but Bonaparte had had enough of Fulton, and would not listen to any petition in his favour, expressing himself in the following terms:—"There are in every capital of Europe numbers of adventurers and inventors who run over the whole world offering to various Sovereigns their pretended inventions, which exist only in their own imaginations. They are so many charlatans or impostors who have but one view—to obtain money. This American is of the number; don't mention him to me again." And once again France threw away her chance of taking the

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lead in this great question of steam navigation. Fulton and Livingston being thus snubbed by France, turned their attention homewards, and Livingston secured a prolongation of the terms of his former privilege, allowing him twenty years' monopoly if in two years he produced a boat having a speed of four miles an hour. Livingston at once ordered a steam-engine from Watt, then in partnership with Boulton in the famous Soho Factory, and Fulton came over to England to supervise its construction.

I have already referred to Fulton's visit to Symington, the date of which seems, on fair authority, to be fixed on July 1801. It would therefore appear quite certain that Fulton's success was in some measure at least assisted by what he saw on board the "Charlotte Dundas," and for the purpose of starting a steamboat on American waters he had recourse to Watt for his engine. Fulton, in December 1806, with Watt's engine, and a number of skilled workmen from the Soho Foundry, then being run by Boulton and Watt, arrived in New York, and it was with these materials that he started business in his own country.

On his arrival he immediately set to work to build his ship to receive the imported engines. This boat was named the "Clermont." She was 150 feet long and 15 broad, and calculated at 150 tons burden. I need not enter into any description of the mechanism employed, beyond mentioning that Fulton employed two paddle-wheels in place of one, as used by Symington, but rather stick to a simple narrative of the boat's success. In August 1807 the "Clermont" was completed, and ready for public trial. His countrymen were extremely sceptical, and openly condemned the attempt as a folly. They seemed to have entirely forgotten the partial success which had been obtained by Fitch, so when Fulton, on the day of trial, went on board his ship he was hooted and jeered at by an immense crowd of spectators. But the signal to start was given, the steamer left the quay and cut her way through the water, regardless of wind or current. The crowd was thunderstruck, and then in another minute the jeers of ridicule were changed to acclamations of enthusiasm and cries of admiration. Colden, in his biography of Fulton,

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says:—"Nothing could surpass the surprise and admiration of those who were the witnesses of this trial; the most incredulous were converted." Fulton, however, perceived during this trip that his paddle-wheel dipped too low in the water. He accordingly withdrew his boat for several days and altered her, and he and Livingston then advertised that in future the "Clermont" would make regular passages between New York and Albany. When the hour arrived for the "Clermont" to start on her first voyage not a passenger appeared, so Fulton made the journey alone with the crew he had engaged to work the boat. The passage—150 miles—was made in thirty-two hours, the boat steaming night and day.

Many amusing accounts are given of the consternation caused by the first passage of this boat during the night along the quiet waters of the river. The glare from the boiler fires, the smoke and sparks from the chimney, the noise of the machinery, and the splash of the paddles were sufficient to appal the most stout-hearted. Sailors of other ships abandoned their post, allowing their boats to drift down the river, while they threw themselves below not to see this terrible apparition; while others threw themselves on deck, praying Providence to deliver them from this monster which advanced upon them, vomiting fire and smoke. On the return journey one passenger turned up, a Frenchman named Andrieux. It is narrated that Andrieux on going on board found Fulton in the cabin in a despondent attitude. "You are going to New York," said Andrieux. "Yes," returned Fulton, that is my intention." "Can you give me a passage on board?" "Certainly," said Fulton, "if you will share the risks with me." "What is the fare?" "Six dollars!" which were then handed by Andrieux to Fulton. Fulton looked at the money in his hand so long that Andrieux fancied there was some mistake, and at last said, "Is that not what you asked?" Fulton, recovering from his reverie, looked up with tears in his eyes. "Pardon me," he said; "I was thinking that these six dollars are the first remuneration I have received after long years of hard labour to develop steam navigation. Were I not too poor, I would consecrate

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it in asking you to share a bottle of wine with me. I hope, however, the next time we meet to make up for my present inability. Four years afterwards they met again, and then Fulton had no difficulty as to the wine.

Steam navigation now began to make its way in America, and we find Fulton constructing a large ship of war for the American Government in 1814, in which the steam-engine was to be applied in a number of novel and ingenious ways; but in 1815 Fulton, from exposure to excessive cold on board ship, was seized with an attack of fever which proved fatal on the 24th February of that year. He had gained for himself such a position that Congress went into mourning for him for thirty days.

While things were progressing in this way in America, very little was being done in our own country; but in 1812 Henry Bell, a Scotchman, launched a little steamboat on the Clyde, and this was the first boat that ran on a regular service in British waters. Symington, in his brief *History of Steam Navigation*, states that, when the "Charlotte Dundas" was lying in a creek of the Canal near Bainsford Drawbridge, Mr Henry Bell from Glasgow was seen frequently to inspect it, and that Bell had also witnessed his experiments in 1789. While, therefore, all praise must be given to Bell for the part he played, it is only just to acknowledge that he certainly had the benefit of Symington's experiences. When Bell's boat, the "Comet," was ready, Bell posted up the following notice in Glasgow:—

"*Steam Passage Boat, 'The Comet,' between Glasgow, Greenock, and Helensburgh, for Passengers only.*

"The Subscriber having, at much expense, fitted up a handsome vessel to ply upon the River Clyde between Glasgow and Greenock—to sail by the power of wind, air, and steam—he intends that the vessel shall leave the Broomielaw on Tuesdays, Thursdays, and Saturdays about mid-day, or at such hour thereafter as may answer from the state of the tide, and to leave Greenock on Mondays, Wednesdays, and Fridays in the morning to suit the tide.

"The elegance, comfort, safety, and speed of this vessel require only to be proved to meet the approbation of the Public, and the Proprietor is determined to do everything in his power to merit public encouragement.

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"The terms are for the present fixed at 4s. for the best cabin and 3s. the second, but beyond these rates nothing is to be allowed to servants or any other person employed about the vessel.

"The Subscriber continues his Establishment at Helensburgh Baths the same as for years past, and, on the 'Comet's' arrival at Greenock, a vessel will be in readiness to convey any passengers that intend visiting Helensburgh.

"Passengers by the 'Comet' will receive information of the hours of sailing by applying at Mr Thomas Stewart's, Bookseller Square, and at Mrs Blackley's, East Quayhead, Greenock; or at Mr Houston's office, Broomielaw.

"HENRY BELL.

"HELENSBURGH BATHS, *5th August* 1812."

It was long, however, before the public looked with confidence on this scheme, and it was only after Bell had taken a tour round the shores of England and Scotland that the good people of Glasgow trusted themselves in any number to his care in making their voyage "doon the watter."

In 1815 Bell constructed and launched the "Rob Roy," a 90-ton boat, with 30 h.p. engine, which commenced to make the passage between Glasgow and Belfast, and in the autumn of the same year several other ships were constructed by him and sent to various ports in England. The Clyde, therefore, certainly has the credit of having initiated steam-ship building for navigation in English waters, and Bell did for England what Fulton had done for America. Following Bell's example, we have Dawson of Belfast, Laurence of Bristol, Thomson of Glasgow—all engaged in building steamers. In 1811 the "Margery" was built on the Clyde, and shortly afterwards taken to London, and began to ply between London and Gravesend; but in the summer of 1816 the French, not having yet succeeded in obtaining from their own engineers a successful boat, sent over to this country and bought the "Margery." The new proprietors immediately changed her name to L'Elise, and prepared to cross the Channel, and notwithstanding extremely unpropitious weather, the boat reached Havre in safety, and was plied for some years successfully on the Seine.

From this date the number of eminent men who have entered the ranks of shipbuilders and engineers becomes so great that it is impossible for me to continue further any-

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thing like a general outline of the history of steam-navigation, and to do so would be quite beyond the scope of my paper, my object this evening being not so much to follow up that history in its entirety as to give you, although in a very imperfect manner, a glimpse at the difficulties and the impediments which surrounded those early scientific workers. Amongst the memorable names I have mentioned to you, most have failed, utterly failed, to bring their ideas to a practical issue—nearly all died poor, some in absolute misery. But it is not for us to make light of such failures, or to tender homage only to those who succeeded. The successes we have noticed were built up on the failures which had preceded them. Each failure taught its own lessons, and if we cannot congratulate many of those early scientific martyrs—for they were nothing short of martyrs in a good cause—on the success which attended their labours, we can at least extend to their memory a reverent sympathy. Let us choose what branch of mechanical or natural science we may, if we examine into its history we will find the same thing occurring over and over again—intelligence struggling with ignorance, truth striving to overthrow fallacy and fanaticism. It seems to me that the study of such histories as I have touched on this evening can only be productive of good. We see in the lives of these early workers that they were met with what may seem to us to be exaggerated difficulties, preposterous indifference, and shameful neglect. But consider the times in which they lived, the general state of education, the almost absolute want of any system of intercommunication. Compare these with the corresponding state of matters in our day, with our schools in every village, our railways, our newspapers, journals, and cheap literature, our postal system, our telegraphs and telephones, and let us ask ourselves are we yet emancipated from prejudice and fanaticism. If we are to break down these, we can have no better preparation than a careful study of the past and an earnest desire for truth in the future.

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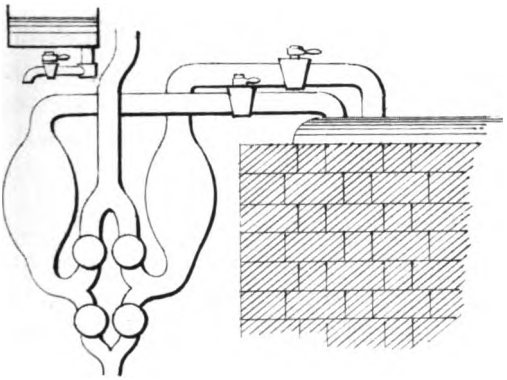

FIG 2

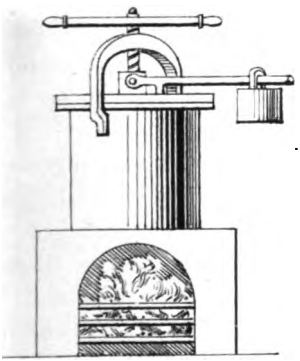

FIG 4

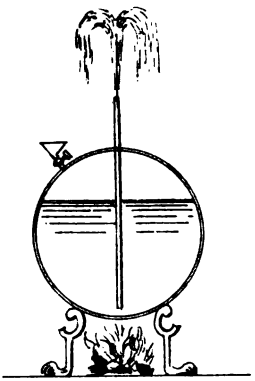

FIG 1

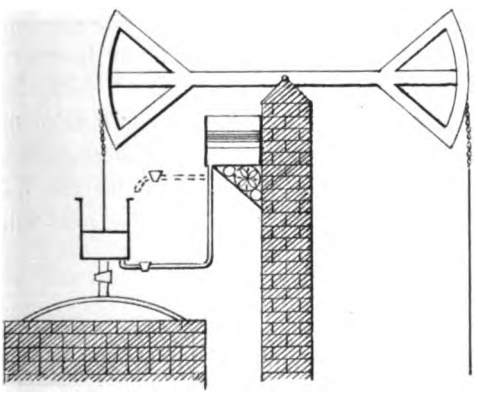

FIG 3

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On the Kettering Sewage Works. By Wm. Fairley, Assoc. M. Inst. C.E., F.G.S.*

The town of Kettering, County of Northampton, is first mentioned in history about the year 950 A.D., and was called in Saxon times Cytringan.

Situated seventy-four miles N.W. of London, on the main line of the Midland Railway, during the past ten years it has advanced in population at a remarkable rate.

In 1801 the population of the whole parish was only 3011, in 1851 it was 5198, in 1881 it was 11,094, and at the present time the population is roughly computed at 20,000.

The staple trade is the manufacture of boots and the preparation of leather.

During the past two years upwards of a dozen boot factories have been erected, many of them being of large dimensions, fitted up with all the latest kinds of machinery. At the present time there are in the town upwards of 100 firms engaged in the boot trade.

In 1872 the district was constituted to be governed by a Local Board or Council, and works of sanitary improvement have been carried out from that time up to the present date, including, among other works, a system of main sewers and disposal works.

The town stands upon a hill, main intercepting sewers 3 ft. 6 in. to 2 ft. diameter running along either side, and catching up the sewage draining down the adjacent slopes. These interceptors join together about a mile south of the town, and enter the sewage disposal works in one culvert.

At present one system of sewers carry off both sewage and storm water, but a beginning has been made to construct a separate system for storm and road water, and the Board have decided that all new streets shall in future have a dual system of sewers,—that is, one set of pipes for the sewage and another for the rain water, the latter discharging direct into the nearest convenient water-course.

* Read and illustrated before the Society on 23rd February 1891.

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Up to 1874 there were two small sewage disposal works, one on either side of the town, each dealing with the discharge from the slope adjacent to it.

In 1884 it was decided to have works at only one point for dealing with the water, and for this purpose the sewage system was continued as already mentioned, and the present works founded.

In the beginning of 1890, when the author took charge, it was evident that the works were quite inadequate for the population, and instructions were given to prepare plans for additional tanks, and also a new process for dealing with the sludge. The new works were at once put in hand and carried out with the greatest despatch.

The process in use up to 1890 was similar to that used at Bradford, namely, precipitation by lime and a subsequent filtration through beds of coke, but the effluent was not very good, being turbid and discoloured.

The coke filters were a most costly and unsatisfactory filtering agent, requiring continual attention and cleansing. Usually after being in use for a few days they got quite foul, and did the effluent more harm than good.

The sludge precipitated in the bottoms of the tanks, after gravitating to the sludge-pit, was pumped up by a centrifugal pump into large backs or earth-beds, each measuring about $60 \times 30 \times 3$ feet deep, covering upwards of an acre of ground. After lying in these beds for possibly a month or more, and being sun-dried, it was dug out, and placed in heaps at the sides, to be further dried, until sufficiently solid to be carted away by farmers.

The stench arising in the summer-time from these large expanses of putrid mud was most disagreeable, and the precincts of the works were kept untidy and dirty. At times considerable difficulty arose in finding accommodation for the sludge, when, as will always occur, there was no demand for it by the farmers.

The new works which the author has put down comprise, (1) Three additional precipitation tanks, (2) Clear-water channel, (3) New storm overflows, to lead the storm water on to the land instead of direct to the brook as formerly, and

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(4) Pressing machinery for dealing with the sludge, and entirely doing away with the open drying-beds and accompanying nuisance.

It should have been mentioned that there is about four acres of land drained with 2½-inch tile-drains, and planted with osiers, for filtering the effluent or storm water. By the removal of the old sludge-beds an additional area will be made available for this purpose, but the land, being clay, is very unsuitable for irrigation. The surface cracks in summer to a considerable depth, so that any water put on simply flows direct through to the under drains without being in any way purified. The land was formerly let to a farmer, but is now in the hands of the Board.

It is simply impossible to conduct irrigation on land for the purpose of really purifying sewage, if the land is let out to be cropped by other parties, as the interest of the agriculturalist is not to purify sewage, but to get a good crop; and in many seasons the quality of the crop has to be a secondary consideration, if the effluent is to be up to the standard.

The works at present comprise eight precipitating tanks—five old, 40 × 25 ft. each; three new, 80 × 30 ft. each; connecting culverts, screening channel, liming machinery, sludge-pressing machinery, and storm overflows.

Tanks.

The old tanks were each 40 × 25 ft. and 5 ft. 3 in. deep at one end and 6 ft. 9 in. at the other, each tank being fitted with a 2-ft. inlet sluice for admitting the sewage, a 12-in. sludge sluice for taking off the sludge to an underground conduit 2 ft. 6 in. diameter leading to the sludge-pit, and a 9-in. sluice with floating arm for taking off the clarified water.

The new tanks are each 80 × 30 ft. with sluices as above, and are built of 14-in. brickwork laid in Portland cement mortar 2 to 1, with blue Staffordshire coping, the floor 9-in. concrete (cement) with 4½-in. brick on edge, the whole floated over with cement.

The fall in the new tanks to the sludge-outlet is 1 in 60, and is found to be sufficient.

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The old tanks have a fall of 1 in 27. This is excessive, and is a great disadvantage in cleaning out the sludge, as it causes a large quantity of water to be left in the tank on the top of the sludge, which has to be pumped out and purified again.

The tanks were formerly worked on what is known as the intermittent system, that is, one tank is filled and allowed a certain time to settle, and then let off, another tank having been filled meanwhile, and so on, one after the other, always one filling, a certain number being emptied, and a number settling. This entails considerable labour in working the sluice, and means that one or more of the tanks must always be empty.

As now arranged, weirs 8 feet wide, laid with white glazed brick sills, have been cut into the walls as shown at each end alternately, so that the sewage, after being screened and having the chemicals added to it, flows through the whole set continuously. The quantity of sewage coming in from the sewers displaces a corresponding quantity in the first tank, and that flows into the second, and so on to the last tank; the outflow of the effluent at one end corresponds with the inflow of sewage at the other. Since this system has been adopted, the convenience and saving of labour has been very evident; and although the intermittent system has many advantages, the continuous flow is eminently convenient.

The capacity of the old tanks is 100,000 gallons, and of the three new ones 150,000 gallons.

This is a small-tank capacity for the sewage flow, which averages 500 gallons per minute, therefore a further addition to the tanks would be a considerable advantage.

Buildings and Machinery.

The sewage enters the works by a 3-ft. 6-in. barrel culvert, and passes through a screening-channel 4 ft. wide. This channel has three wrought-iron screens, with a shoe on the foot of each, and the bars 3 inches apart in the first, diminishing to half an inch at the last. At this point all the coarser floating matter, rags, &c., are caught, the screens being periodically cleaned with a handrake.

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The sewage channel leading to the tanks runs off from this point right and left, along the top end of the whole set.

Agitators have been placed at the end of the screens so as to thoroughly mix the chemicals with the sewage.

The sewage channel is 4 feet wide, with walls of 14-in. brickwork in cement, coped with blue Staffordshire coping, and rests on a bed of concrete 3 to 5 feet deep, in which is encased the sludge-drain. This in the old tanks is a brick culvert 2 ft. 6 in. diameter, but for the new tanks it is formed with 18-in. stoneware piping.

Manholes have been placed on the new portion so as to facilitate repairs or the clearance of any stoppage.

All tanks except No. 1 of the new set have 2-ft. openings, and iron sluices with ratchet and pinion opening from the sewage channel, the tank mentioned having a 4-ft. opening and iron penstock with screw and wheel.

From the lower end of each tank, a 12-in. sluice and opening connects it with the sludge-drain, the spindle from the sluice being carried up the level of the walls, and works with screw and wheel.

To empty the tanks a 9-in. sluice fitted with floating decanting arm is fitted at the end next to the clear-water channel. This drains off the water to the level of the top end of the tank, the mouth of the arm being kept just below water-level by means of a cylindrical air-vessel, so that top water only is drawn off, the arm sinking as the water-level is lowered.

The block of buildings alongside the tanks comprise two boiler-houses, engine-room, and liming-room.

There are two Cornish boilers, one 12 ft. 3 in. long, 4 ft. diameter, with 28-in. flue, the other 14 ft. × 4 ft. 6-in. and 30-in. flue.

One boiler is under steam at a time, the other being laid off for cleaning and repairs. The usual time one boiler is under steam is from four to six weeks; the cleaning out requires to be regular, as the water used for feeding is supplied by a well fed from the effluent channel, and is therefore highly charged with lime and other chemical ingredients.

The engine-room contains the engine supplying power to work all the machinery on the works; it is an ordinary

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horizontal cylinder engine 18-in. × 9 in. with adjustable cut-off gearing, and runs about 70 revolutions per minute with a pressure of 40 lbs. of steam.

The engine is connected by link-gearing to the running shaft in the lime-house. From this shaft, which is 2⅝-in. diameter, the lime-mills, the air-compressor, a centrifugal pump formerly used for the sludge, and the pump for lifting the effluent on to the land, are driven.

The exhaust from the engine is utilised in working an exhaust injector to feed the boilers.

Besides the engine, there is an air-compressor and air-receiver, which will be described with the sludge-pressing plant, and a donkey-pump by Tangye, with steam cylinder 10 in. × 6 in., which pumps water to a tank used for feeding the lime-mixers, the boilers, and general purposes.

The liming-house contains a pair of lime-mixers with rotary agitators driven by bevelled gear from the main shaft. The pans are each 3 ft. 6 in. diameter and 2 ft. 6 in. deep.

The apparatus for feeding the lime consists of a hopper placed between the two mixers, with a revolving shaft driven by a belt from the main shaft, having knives placed on it, so that it is constantly carrying forward the lime to two outlets, one at either end, placed over the pans.

Water is fed by the overhead tank already mentioned, and the milk of lime flows out by a wooden trough to the point of mixing at the end of the screening-channel.

One mill only is presently in use, and is found to be sufficient to feed in the desired quantity.

Clear-Water Channel.

The clear-water channel runs along the whole length of the tanks at the opposite end from the sewage channel, and was formerly only 3 feet wide. It has now been widened to 6 feet, and laid with white glazed bricks at several points to show the clearness of the effluent.

At one end of this channel there is a bell centrifugal pump driven by a 2½-in. shaft, 60 feet long, laid from the lime-house and driven by a 5-in. belt from the running shaft. This pump can be used at any time for lifting the effluent on

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to the land for filtration, a height of 4 feet; but, although it does its work fairly well, it is difficult to drive and keep in order.

The chemicals used at the present moment are lime and alumina ferric cyanide.

The process is as follows:—After the sewage has passed through the screens, milk of lime is added in the proportion of from 6 to 10 grains per gallon. After receiving the lime it is thoroughly mixed by the agitators, and flows along the channel into No. 1 tank, across which, near the upper end, is stretched a screen of cocoa matting, preventing froth and any large floating matter which has passed the screening channel from entering the set of tanks. This first tank may be called the roughing tank, the bulk of the solid matter being precipitated. After flowing through No. 1, it passes over a weir 8 feet wide to the next. On this weir are placed the iron trays containing the alumina ferric, broken up into lumps of about 3 lbs. each; the alumina, which is soluble, is dissolved by the sewage, flowing over the weir. After this the sewage flows through the whole set of tanks by the weirs, which are so arranged as to create a zigzag flow. On reaching the last of the old set, or No. 5, it may be allowed to flow into the clear-water channel by two 4-ft. weirs, one on either side of the outlet sluice, or it may be passed over a weir of 10 feet wide in the side, and led along a covered channel 3 feet wide into the new tanks, on passing through which it flows over two weirs into the clear channel, down to the bell-pump, where, if desired, it can be pumped on to the land or led direct into the brook by underground conduits.

In cases of heavy rains the old tanks are worked as one set, and the new as another set, the sewage being divided either way at the agitators. Of course, in time of storms the effluent is more or less discoloured.

The lime used is the ordinary lime of the district, and is delivered at the works in loads of 20 to 30 cwt. at 12s. per ton, and is slaked and sifted before being used in the lime-pans.

The alumina is at present procured from Spence & Co., Manchester, and costs in truck loads at the station £3 per

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ton; it is in a convenient form, viz., 56 lb. slabs ready to store and pile. The alumina compounds of other makers have been tried, but although that of Spence is more expensive, it has the advantage of not wasting so readily on exposure to the air, and of being in a more portable and convenient form.

For several months the author tried the black ash or sulphurous powder, manufactured by Mr Hanson, Wakefield, the quantities used being 10 grains of lime and 6 grains sulphurous powder per gallon.

The method of using it was as follows:—The lime was added as already described, and the black ash mixed with water in the spare lime-pan, from which it was fed by a 4-inch pipe to a point before the sewage was screened. This was the reverse of what has been done at a number of places, viz., putting the powder before the lime; but Mr Hanson advised so. Very good results were obtained, but owing to the difficulty of getting the powder dissolved, the alum has been resumed in the meantime. The lime-pan used, with its rotary agitators, seemed to give the powder too little time to dissolve.

The best effluent the author has seen from works with a chemical process in use was at Leyton, E., where lime and sulphurous powder are used.

The staff required for regular working are two engine-men and two tank-men, divided into two shifts of eight and ten hours respectively. The engine-men reside at the works and have cottages provided by the Board.

Sludge.

As already stated, the method formerly in use for dealing with the sludge deposited in the tanks was to pump it out into large earth tanks, and allow it to dry in the sun and air, after which it was dug out to allow it to dry further, until it was solid enough to be carted away.

The sludge is now dealt with by special plant, and pressed by air at high pressure, the process being as follows:—

After a tank has had the water drained off to the level of the floor at the sluice end, the sludge is brushed out and gravitates to the sludge-pit. This pit is 15 ft. × 20 ft. at

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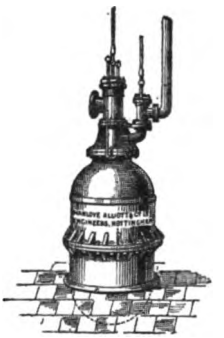
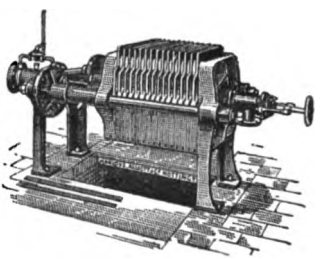
the top, 12 ft. deep below the surface, built of 14-in. brickwork, backed with puddle, and faced with blue brick.

From this pit a 6-in. iron pipe is laid to the pressing-house, in which is a pit 23 ft. deep below the surface, formed of 14-in. brickwork in cement, with a backing of 6 to 9 inches of cement concrete, and having 14-in. brick piers at the centre of each side wall. The dimensions of the pit are 9 ft. × 4 ft. 6 in. inside, and it contains two iron cylinders or rams; each ram is 6 ft. long × 3 ft. in diameter, bedded in cement concrete. The pipe from the sludge-pit is connected to each ram by a Y-piece, and has a sluice for stopping or regulating the flow of the sludge which gravitates in.



From each ram a 3-in. pipe is led up to the level of the floor of the pressing-house, and thence below the floor up to the presses, of which there are two.

The presses, better understood from the drawing, consist of a massive cast-iron frame with a fixed head next to the sludge-pipe.



The head-piece at the other end can be moved out and in by a small air-cylinder, fed by air from the same source as that used for pressing. Between the fixed and movable heads are thirty iron plates resting on either side by lugs. Each plate is dished and grooved, and has a hole in the centre. Canvas cloths are placed over the plate, so that each has, so to speak, a canvas envelope; at the bottom corner there are small drainage pipes leading into a gutter, which has an outlet into the sewer.

Various methods have been adopted to force the sludge into the press; sometimes a steam-pump is used, or direct steam pressure, and in others compressed air. The latter has been adopted at Kettering, after investigating the advantages and disadvantages of the different methods.

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The usual method is to have a separate air-compressing engine and pump; but as the power of the engine at the works was not fully utilised, it was decided to place the compressor in the engine-room, and drive it by a belt from the shaft in the lime-house. The compressor is vertical, having 9-in. stroke, 6½-in. bore, driven by a 2-ft. pulley and 3-in. belt, the whole balanced by a heavy fly-wheel, 4 ft. diameter. The pumping-barrel is fitted with a controlling-valve, so that the pump may pump to waste, and not to the receiver, without stopping or throwing out of gear; water is circulated round the pump-barrel from the tank in the lime-house.

The air is delivered by a 1½-in. pipe to a main receiver 6 ft. 6 in. high, and 2 ft. 6 in. diameter, fitted with pressure-gauge and safety-valve to blow off at 100 lbs. per square inch. From the receiver a 1½-in. pipe is led to the pressing-house, and connected to the rams.

Above the ram-pit there is a gauge-board, with gauges to show the pressure of the air in the pipes, and in the rams and receiver, the cocks and gauges being on the one board, so that one man may control all.

A lime-pan is fixed on the top of the ram-pit, and connected to each ram. This pan can be fed from the mill, mixing lime for the sewage in the liming-house, and is connected to it by a 2-in. pipe led underground. The operation is as follows:—The sludge from the precipitating tank gravitates by the special drain to the sludge-pit, where it is allowed to settle, a certain amount of water rising to the top. This water can be taken off by a floating arm and the water delivered back to the sewer in the following manner:—

The attendant shuts the connection between the filter-press and the rams, and opens the sluice attached to the floating arm, the water draining from the surface into each of the sludge-rams. As soon as they are full he stops the flow, and opens the air-cock, admitting air at about 10 lbs. per square inch pressure. This forces the water to the surface, from whence it is led by a special pipe outside the building to the drain leading back to the sewer. As soon as each ram has been emptied, and the air brought down to atmospheric

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pressure, he again fills by the floating arm, repeating the operation.

For pressing and filtering the sludge, the method of working is equally simple. First, a charge of milk of lime equal to about two buckets is put into the lime-pan, shown on the top of the ram-pit, and allowed to flow down into the ram. The sluice in the sludge-pit is then opened, and the semi-liquid sludge allowed to flow in until the ram is filled up. The sluice is then shut, and the connection between the filter press and the ram opened (the press having previously been screwed up as tightly as possible). Air is then admitted from the receiver in the engine-room, at a pressure of from 80 to 100 lbs. per square inch on the top of the sludge, and forces it up by the connecting-pipe into the chambers between the canvas sacking in the press. This pressure is continued from fifty to sixty minutes. The water runs by the sacking into special grooves, and draining outside into a cast-iron gutter, from which it is conveyed outside the building, and hence by a drain into the sewer, to pass again through the tanks.

In about fifty minutes the pressure is taken off the ram. The movable head of the press is forced back by the air-cylinder, and the plates forming the cells of the press pulled apart one by one, the compressed sludge, in a form like oil-cake, falling down into an iron bogie truck, holding about 10 cwt. Wooden paddles are used to scrape the cloths clean, but generally the pressed cakes fall out clear, unless wet. As soon as the charge has been transferred to the bogie truck the press is again closed and screwed, after which it is ready for another charge, the cake in the bogie being run out on a tramway of 24-in. gauge and tipped.

The sludge from the press is in such a state that it can be easily stacked in a cart and removed.

The quantity of sludge in each charge is about 2 tons, and contains about 90 per cent. of water. Of this only about 8 cwt. is left as pressed sludge,—that is to say, that 1 ton of wet sludge can be reduced to 4 cwt. of portable cake.

The cost is about 1s. 9d. per ton of cake produced; and at present, although the presses are being worked six days a week for eleven hours per day, this is because of a considerable

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amount of sludge which has been lying back in the tanks, and is now being dealt with; but in ordinary work, for a population of 20,000, all pressing should be done in three or four days a week.

The item for removal of canvas cloths forms a considerable part of the expense, the cost of the canvas and making up being about 1s. 2d. each chamber of press.

The makers of the presses and machinery were Messrs Manlove, Alliott & Co., Nottingham, that firm making a speciality of this kind of work. The cost was £700.

The labour employed is unskilled labour, being, in fact, the man formerly engaged digging out the sludge under the old system. The air-compressor and receiver being placed in the engine-room, are under the eye of the engine-man on duty, and he can see at once by the gauges the state of the air in the rams and presses.

This is the only case the author knows of in which the vertical compressor driven by belting is used at works of this kind, the general method being to have a separate engine in the pressing-room, but the engine on the works not having very heavy work to do, in proportion with its power, it was considered advisable to utilise it, although doubt was raised as to its being sufficient. In working, however, it has done all that is required of it, and the disadvantage of having another engine to keep up and repair was avoided. In addition to this work on the engine, a set of agitators have been put down, and they are also driven from it by chain gearing, the distance between being 36 feet.

Storm Overflow.

The 3-ft. 6-in. sewer leading into the works is continued down to the stream running along the west side of the land. An iron penstock turned the flow of sewage into the screening channel, but in the event of more water coming down, which occurs always with heavy rains, than the tanks were able to accommodate, the sewage overflowed the penstock, and thence by the culvert direct into the brook.

The present arrangement prevents any direct flow to the stream. A slanting weir 2 ft. 3 in. high was built in the

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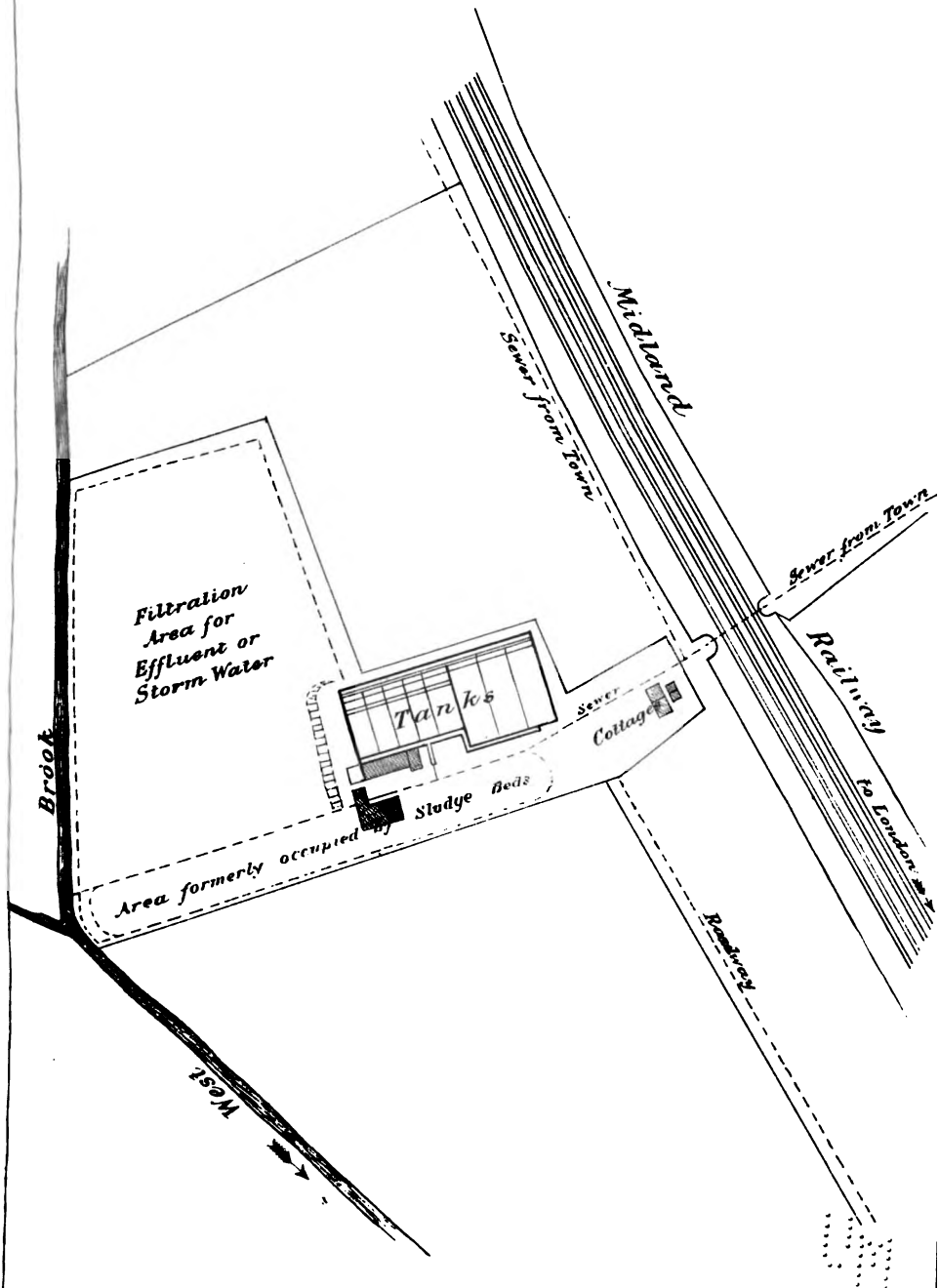
— Kettering Sewage Disposal Works. —

General Plan



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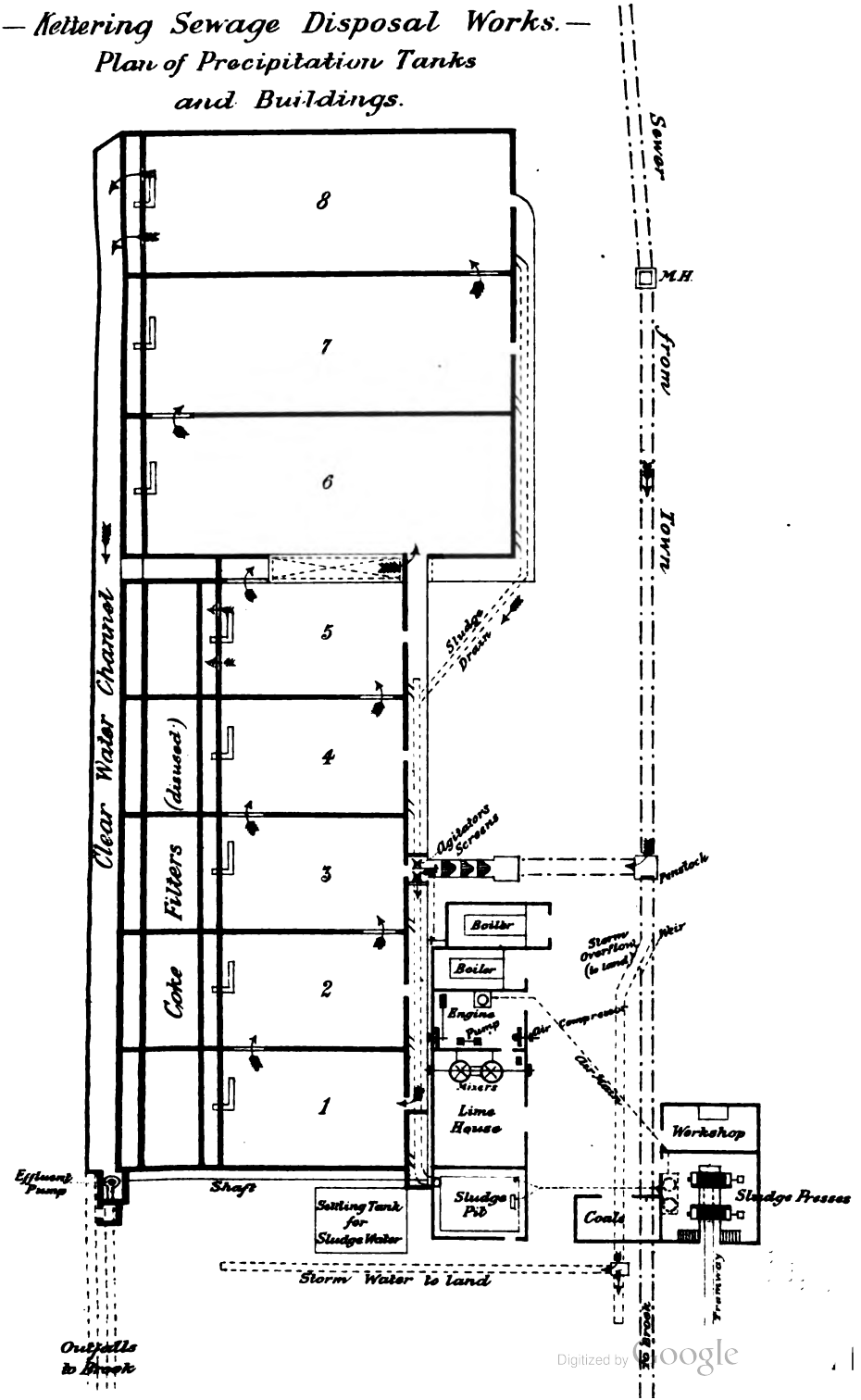
— Kettering Sewage Disposal Works. —

Plan of Precipitation Tanks and Buildings.



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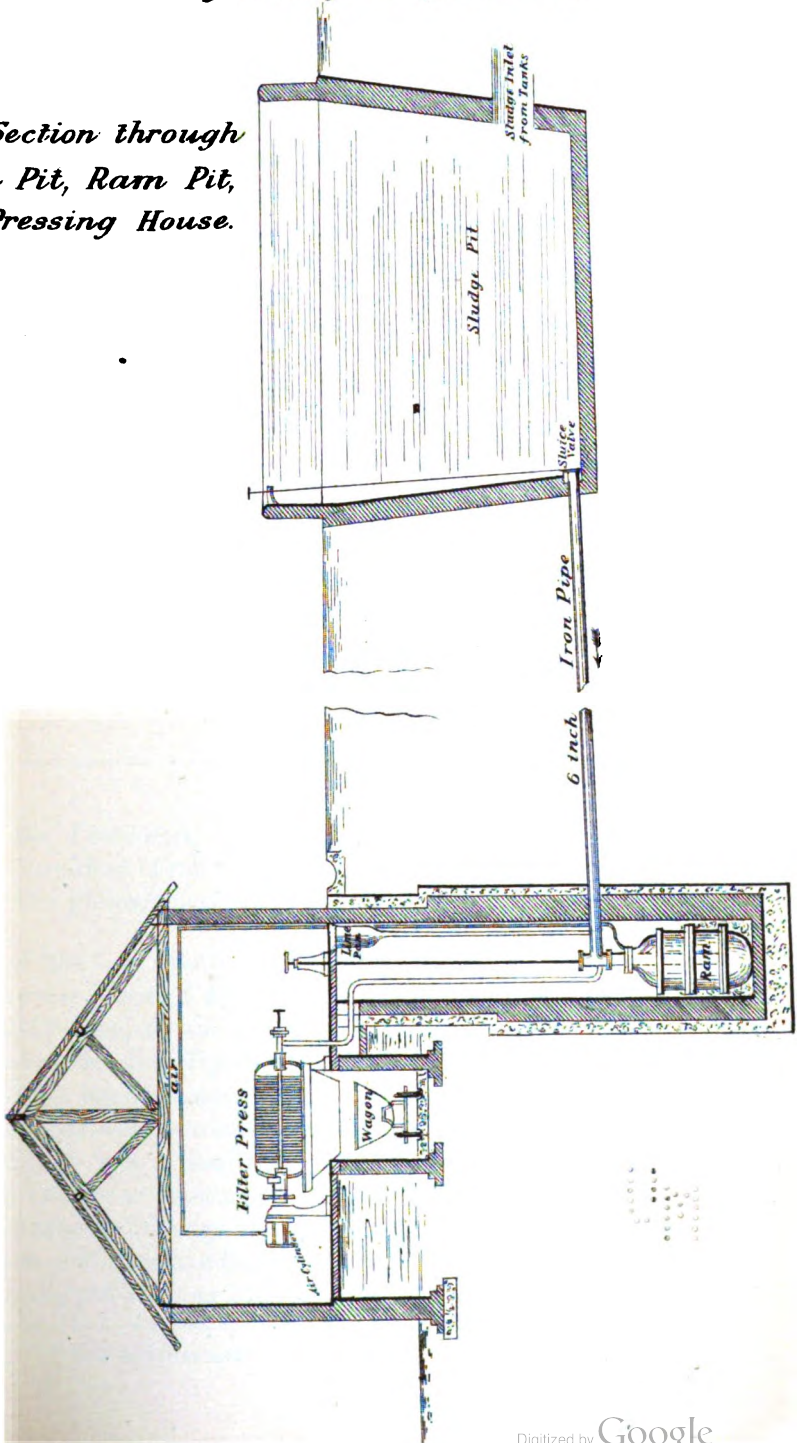
— Kettering Sewage Disposal Works —

Cross Section through Sludge Pit, Ram Pit, and Pressing House.



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culvert, about 12 feet on the stream side of the penstock, and a new 2-ft. culvert built of brick in cement leading on to the land. Any overflow now in passing the penstock is diverted by the weir, and turned down the new culvert, and allowed to flow on to a portion of the land which has been prepared, so that it is roughly filtered before reaching the water-course. This new overflow has had to be laid almost level, owing to the level of the land; but since it has been erected one or two heavy rains during the night have shown by the deposit left on the land what had formerly found its way into the stream.

The whole works and machinery have now been working for some time. The effluent is clear and odourless, but there can be no doubt that if the town increases in the next five years as it has done in the past, either additional tank accommodation will require to be provided, or additional land secured to form filtration areas.

The total cost of the works, exclusive of interest on loans for land and buildings, amounts annually to about £700. Of this about £150 is for chemicals.

On the Ventilation of Schools. By W. P. Buchan, S.E., President of the Sanitary and Social Economy Section of the Philosophical Society of Glasgow.*

For the last twenty years, and in great measure owing to the severe illness of His Royal Highness the Prince of Wales in 1871—due, as was supposed, to the influence of sewage-polluted air—the subject of the drainage of houses and other buildings has commanded a large amount of public attention. It is somewhat curious, however, that while the general public, as well as sanitarians and the law of the kingdom, have become so exacting as to the style and condition of the appliances and fittings connected with the liquid drainage of houses and other buildings inhabited or temporarily occupied by man, yet that so little consideration should have been

* Read and illustrated before the Society, 13th April 1891.

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given to supplying suitable provision for carrying out the ærial drainage of the same structures.

There is something wrong here, and the sooner it is rectified the better for the whole community and the progress of the race.

Fish live in the liquid ocean, of which rivers and lakes may be said to be portions; and we all know that should these rivers or lakes be polluted by the discharge of offensive waters into them, the fish soon become diseased, and may even die and disappear.

The Clyde, *e.g.*, used to be famed for its salmon, and they were so plentiful that in the old indentures of the Glasgow apprentices a clause was inserted that they should not get salmon to dinner too often in the week. Now, however, the Clyde at and below Glasgow has become a veritable Black Hole of Calcutta for the salmon. They could not live in the foul water.

Human beings also live in an ocean, but the fluid in this case is ærial, not liquid. All the same, contamination of its bays and lochs, as in our houses, schools, work-rooms, churches, and halls, &c., produces evil results. Disease and death are the natural consequences of breathing a polluted atmosphere out of the water as well as in it. The high percentage of deaths due to pulmonary diseases shows the powerful effect our atmospheric environment has. In pure self-defence, therefore, the nature, condition, and effect of this environment is worthy of our most serious consideration; and in this connection it should be borne in mind that the deaths from the highly sensational cases of quick poisoning in the Black Hole at Calcutta and the steamer Londonderry are the merest fraction of the millions of victims of slow poisoning in ordinary life.

Nothing is surer than that millions of our fellow-beings, young and old, *and especially the former*, are continually being prematurely sent into their graves from preventable causes, and of these preventable causes the unhygienic condition of the atmosphere lived in forms a large proportion.

It is beyond the scope of this present paper to enter fully into this matter, nor does time at present permit, so I come

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at once to my particular subject or text, viz., the ventilation, or hygienic conditions of the atmosphere, of our schools.

I have recently examined a number of Board Schools, especially in Glasgow, and also some in the country; while a few days ago, thanks to the courtesy of Mr Macrae, the Chairman of your Board, and to the kind assistance of Mr James Thomson, C.E., I have seen a few of the Edinburgh Board Schools.

As to the Glasgow Board Schools, a number of which are three-flatted and serve for a large number of scholars, these are all automatically ventilated; and I am sorry to say that, so far as I could judge of those I saw, the ventilation was not up to the mark in any of them. It might have been expected that, considering the costly character of the buildings and the uses for which they were erected, that such a vital feature as the ventilation would have been attended to, and that by an expert; but no evidence of such could be seen, even although the Board had often taken this matter out of the hands of the architects.

The following sketches will show how the work has been done at a number of the schools, and they will enable you to understand what to avoid.

In one school the provision for carrying off the vitiated air is as per A and B in fig. 1, where the opening A in the

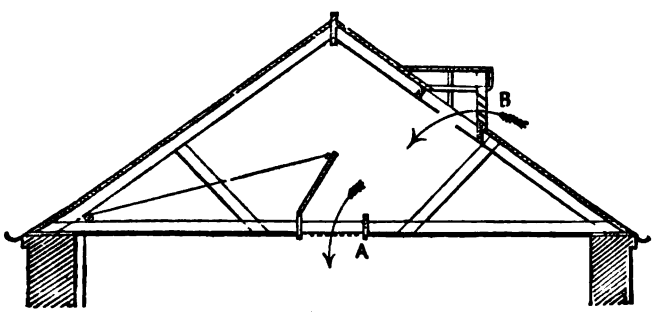

Fig. 1.

ceiling merely communicates with the garret, while to ventilate this garret, or space below the roof, the provision shown at B exists; but it often happens that instead of the vitiated air going out at A and B as wished, the cold air blows in and

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down upon the heads of the teacher and scholars, so that the valve has to be closed. The windows have often to be opened to give relief, but the result is most unsatisfactory, the teachers stating, "We are never free of colds here;" while one young lady remarked, "I am just newly back from being a month off with rheumatic fever."

At another school—a West-end one, too—of two flats, there was no provision for the outlet ventilation by means of either flues or pipes in the lower flat, while the windows

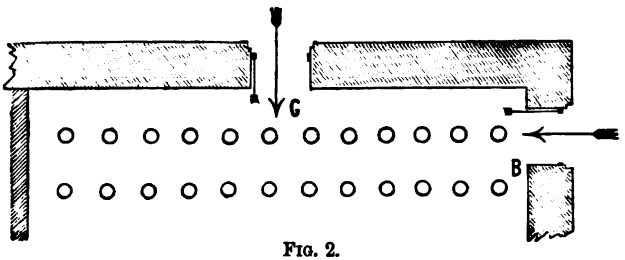

FIG. 2.

were hinged casement-fashion, and opened inwards like doors, in one case as per B, fig. 2, allowing the air to blow in on the sides of the boys, and in another room to blow in on the backs of the girls, as per G, fig. 2.

In the upper flat of this school some provision for ventilation was fitted in by means of pipes off the ceiling, although very inadequate for the purpose. In one large room, for 110 pupils, there was only one outlet in the ceiling, with a 12-inch diameter pipe above it, as shown at C, fig. 3, which pipe led up to a small wind-acting ventilator on the ridge. This 12-inch pipe only gave 1 square inch of outlet area for each pupil, whereas in a school at Galashiels, for a room also for 100 pupils, the main outlet pipe is 22 inches diameter as per T, fig. 3, which allows nearly $3\frac{1}{2}$ square inches for each pupil. Instead of the Glasgow City School having less than a third of what the small town school has, it ought to have more than it. The Galashiels large pipe has also good

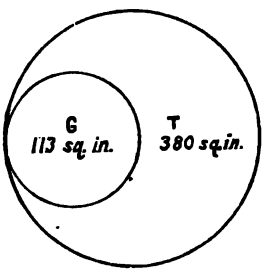

FIG. 3.

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automatic provision against down-draught, while the Glasgow school wants that.

At other three new schools opened so recently as last year the provision for carrying off the vitiated air and vapours, &c., given off from the lungs and bodies of the children, is not only far too meagre, but the pipes are badly arranged, as shown in fig. 4. In this case, as the same wind-acting ventilator on the ridge serves for the short smooth pipe A from the top-flat room, and also for the other rooms below, while the pipe A nearest the ventilator, instead of being smaller than the others further away, is either of the same diameter or larger, it follows that the ventilator will often get its principal supply from the top-flat-room pipe near it, and very little from the rooms below, which are so much further away, and from which the pipes are so small, being only 9 or 10 inches in diameter, while the top-flat pipe is 10 or 11 inches in diameter. The top-flat room should not have been connected into the same ventilator as the lower-flat rooms. This is an interesting specimen of "How not to do it."*

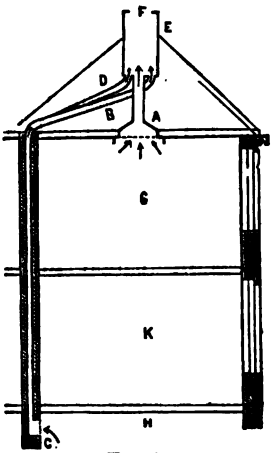

FIG. 4.

In another very large school, the pipes of which are also far too small and go up something in the same manner, the wind-acting ventilators are actually fixed up at the back of the roof, and in part below the ridge, so as not to be seen, and not to break the line of the ridge. I wonder if the architect who adopts such a foolish plan as this for a school would think it an improvement upon his own appearance if his nose were pressed down flat upon his face!

It is high time for it to be understood that ventilators have as good a right to be seen as chimneys, while, when used, they ought to be of a size and construction commensurate with the work to be done.

* In one test I made of fig. 4 style, the outlet at the lower opening C was only one-tenth of the speed of the air going up the A opening.

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I never imagined, until I examined these schools a few months ago, that the ventilation was being carried out so badly. I supposed that as the Board were doing so many, they would be going on making one improvement after another upon them; instead of that, they seem to me to have been working away very much in a circle.

I wrote the Board lately, pointing out some of the mistakes, and the plans of a large new three-flatted school were sent to me for my opinion about the ventilation. I have recommended mechanical means to be used, but whether this recommendation will be adopted or not remains to be seen.

Owing to the inefficient means provided for the ventilation, it is a common practice for the windows to be opened, the effect of which must often be very detrimental to the children.

When visiting one new school, the windows were open in a certain room. I shut them, and went out for a few minutes. When I came back, the windows were down from the top again, the teacher stating that the ventilation was so bad, if the windows were shut, that she could not go on with her teaching. I am inclined to think that this opening of the windows in so many cases when the children are in the school must quietly kill a number of them. As to this, Professor Hay, Medical Officer of Health for Aberdeen, stated before the Sanitary Association of Scotland last July that the death-rate among children between ten and fifteen had actually increased, while nervous disease was also on the increase among children of the school age. The special cause of mortality among them was tubercular disease and diseases of the respiratory organs, and especially among girls between ten and fifteen years of age. To remedy this he says:—"The first and great essential is a sufficiently pure atmosphere within the schoolroom."

I was much struck with Professor Hay's statement that girls suffered more than boys; and the explanation of this seemed to me to come one day I visited the large school in Garnethill, when, on entering a room with a lot of girls in it about eleven to fourteen years old, I found them all sitting with their cloaks off and with their backs to the window,

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which was down from the top a considerable distance, so that, as it appeared to me, these girls might easily get chilled by the cold air from the window blowing in and down upon them, and so colds and lung disease might be the result. The provision for carrying out the vitiated air was far too small.

I might here mention the reason why too small provision, or none at all, for carrying off the vitiated air from schoolrooms has such a bad effect. You may all know that in breathing each of us exhales about one hundred times as much carbonic acid gas as we inhale, consequently a roomful of children, say seventy or eighty, all blowing off at once this large amount of carbonic acid gas into the atmosphere of the room, while at the same time they are consuming the oxygen, soon spoils the air of the room if the exhaled air is not carried off and fresh air allowed to come in in a proper manner to supply its place. The exhaled air is not pure CO_2, but is mixed with vitiated organic matter, which makes it worse. Supposing a schoolroom for 80 children, with a cubic capacity of 11,200 cubic feet, and you wished the atmosphere changed three times an hour. This means carrying off 33,600 cubic feet in that time.* To do that with one 10-inch diameter pipe, the pipe would require to pass up at the rate of 1100 linear feet per minute. But even a first-class wind-acting ventilator could not manage that except during a high wind or storm, and happily these do not occur every day, so that with a speed of 270 linear feet, four 10-inch diameter pipes would be needed. On calm days, again, the outgoing speed would sometimes be less than 270 linear feet per minute, so that the absurdity of putting in one 10-inch diameter or smaller pipe to ventilate this schoolroom is manifest.

Even with mechanical power for the extraction, the outlet

* If 2000 cubic feet of fresh air for each pupil were allowed, as some doctors wish, this would mean 160,000 cubic per hour for the room, or changing the air in the room *fourteen* times in the hour. To do this would require strong mechanical power. This is not necessary, however, as, starting with fresh air, it takes some time to deteriorate it, while ample flushing at intervals enables much less to serve well—say one-third.

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opening from a room for eighty pupils is generally much larger than an area of 78 square inches or so.

At Glasgow there is one school the ventilation of which is pretty good, and in which an extraction-fan is used, set up under the roof. This school is in Cecil Street, Hillhead, and is under the Govan School Board. The outlets from some of the rooms are from 7 feet to 6 feet long, and about 6 inches wide. The air-capacity of this school is about 200,000 cubic feet. The fan discharges that amount at its outlet every thirteen minutes, and so changing the air in the school about four and a half times every hour.

Were it not that it is the custom now, at many schools, to open the windows fully at the intervals, in order to flush the rooms, the atmosphere in them would be much worse than it is. I object strongly, however, to it being necessary to open the windows; and *even on cold days, when the children are in*, in order that the teacher may get air sufficiently breathable to be able to teach. Teaching means fitting the children for discharging their duties in after-life, but much of this teaching becomes a mere sham if, in carrying it out, the health of the children is either deteriorated or ruined. Health with many people is their principal capital, and to rob them of this is, in my opinion, one of the meanest and basest of crimes. We seem also to have much to learn yet how much the well-being of the mental depends upon the welfare of the physical.

I have referred to the condition of Glasgow schools; many in the country are as bad, or even worse. In one school I visited the provision for ventilation was so bad that the head teacher told me the children sometimes sickened and had to be sent home, the carbonic acid gas being up to about 40 parts in the 10,000, or ten times the normal amount in fresh air.

About ten days ago, as I intimated at opening, I examined some of your Board Schools here, viz., Dalry, Torphichen Street, Fountainbridge, Lothian Road, Stockbridge, and Canonmills Schools. Now, while I was very much pleased to see the improved style in which the ventilation of Dalry large new school was being provided for (viz., with its fresh-air

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inlets at windows and hot pipes to warm the incoming air, as well as a large 72-inch Blackman exhaust-fan in roof),* I think some of the other schools are not at all up to the mark in respect of their ventilation: *e.g.*, Fountainbridge School, with only a small 6-inch by 4-inch Arnot's valve for a room 30 × 29 ft. for 84 pupils, is not the thing at all; 6 × 4 only gives 24 square inches, whereas I would want 84 × 5 = 420 square inches or so of outlet provision. In this school near the top of the windows there are large pivoted panes, but to open these when the children are in is often dangerous for them, owing to the cold incoming air blowing down upon their bodies.

At the Lothian Road School the provision for ventilation seems to be almost all out of order. Although there are large openings in the ceiling, these in most of the rooms appeared to be closed, and they could not be opened. I understand they allowed down-draughts badly when opened. In one room, with two windows down from the top about two feet, I tested the ceiling outlet with my anemometer, but could not get any indication of a current. It is the custom to have the windows open when the children are in, and I saw this with my own eyes. One parent whose children attend this school complained strongly of his children coming home with colds, and of the children being affected with glandular swellings from that cause. He said the children complained that sometimes the snow came in through the open windows upon their books. I saw a bad style of fresh-air inlet here, viz., in a window a few inches from the boys' heads and below them, so that the incoming air was apt to strike the boys at the back of their necks or heads. I understand about 200 of the pupils were absent in March. These two schools ought to have their ventilation improved as soon as possible.

Stockbridge School is also open to improvement. I do not think it is either a good or safe plan for the children to have large fresh-air inlet gratings, 2 feet by 10 inches deep, set

* The school is not yet quite finished, while the fan was not working when I was there. When it is in proper operation I would like to come back and test its effect.

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vertically in the wall close to the floor, through which the cold air can blow in horizontally upon the children's legs and bodies. There are Arnot's valves in the rooms here, but I understand they do not give satisfaction. They are about 10 × 6 in.

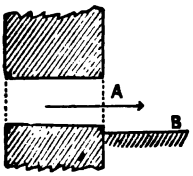

Fig. 5.

As in some of the other schools, there are grates in the Manchester style with a warm-air flue above them, intended to let warmed fresh air into the rooms when the fires are on; but in this school some of these intended warm-air inlets are pasted up, as smoke came out. In some of the rooms the outlets intended to carry off the vitiated air, instead of being up at the ceiling, are about 6 feet down from it, thereby leaving a large foul-air cistern 6 feet deep all the area of the room.

Canonmills School, especially its upper flat, felt better than either Lothian Road, Fountainbridge, or Stockbridge Schools. It is heated by Manchester grates, with warm-air inlets above them, and also with fresh-air inlets direct from the outer air in the window sills, but without any provision for heating the incoming air at them. The hall of the juvenile department in top flat had an 18-inch diameter outlet Archimedian ventilator. The air was going up the ceiling opening at 190 lineal feet per minute.

In the flat below, the outlets, I was informed, in the ceiling communicated with the iron gratings set in the face of the walls at the front and back of the buildings. I would have liked to have felt the air in this school when the children were in.

Torphichen Street School, as far as I could judge of it when empty, seems one of the best of the automatically ventilated schools. The heating of the large lobbies and staircases by the two Musgrave stoves should have a good effect.

In the rooms there are Manchester grates for heating and also helping the ventilation, but with these, when the fires are on, I would expect the draught of the chimney would often be inclined to draw air in at the intended ceiling outlets. Above the Manchester grate in each room there is a warm-air inlet 10 inches by 6 inches, and about 7 feet up from the

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floor. There are Tobin's tubes as inlets 19 × 4 in., about 6 feet high, direct from outside, with no provision for warming the incoming air.

There are flues intended for outlets for the vitiated air from off the ceilings of the rooms with cord-worked valves, but no anti-down draught-valves, I believe. In the top flat I was told that pulling the cord shuts the valve, while in lower rooms pulling the cord was said to open the valve. There were no index-plates on, so the person using such has to depend upon his memory. There ought to be an index-plate fixed on where each cord is pulled from, so that any person working the cord would know what he was doing. Shortly since I had a report sent me that the ventilation provided for a new hall in the middle of England, which was supposed to be well done, had not given satisfaction during a grand ball held in it. I was requested to send a man off at once to make any necessary improvements, at the expense of the people there. The man was sent, and we got a telegram next day, "Ventilation all right; they pulled the cord tight and shut the valve, in place of slackening it to let it fall open." Now all this annoyance and expense was simply caused by the contractor omitting to put on an index-plate with the words "Valve open when cord slack" upon it.

When air is exhaled from the lungs its heat will be about 98°, or between 30° and 40°, generally speaking, warmer than the air in the schoolroom, so that it naturally rises towards the ceiling, consequently, generally speaking, in this country the best place to carry off this exhaled air is at the ceiling, and before it falls to be re-breathed again. This is the reason why ample provision for the outlet ventilation should be provided. I have never seen too much given, but generally far too little—only a fourth, a sixth, or a tenth, or even less of what it should be, and often no special provision at all made.

In regard to the fresh-air inlets, they are often very badly placed, and bad in style, while it is only in rare instances as yet that the incoming fresh air is warmed even in cold weather. I have referred to the provision you have made at the Dalry School for heating the incoming air in the window-bossings. At some other places the dado system of fresh-air

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inlets with hot pipes at the back of the dado has been introduced with beneficial effects. My purpose here to-night was not, however, to show how to do things, but rather to give you some evidence that as things are there is much room for improvement.

The fact of you carrying out the ventilation of Dalry School in a different manner from the way such is done—or not done—in the older schools, tends to show both that you are aware that there is room for improvement, and that you have begun to carry it out. The Dalry School is in the right direction; and after experience has been had of its working, then the old faulty schools should be taken in hand, and made more hygienic for the children and the teachers than they at present are.

Edinburgh is ahead of Glasgow in this respect, although Dundee and Aberdeen, as I understand, are prior to both. At Dundee and Aberdeen the propulsion system of ventilation has been introduced, but at Dalry you have gone in for the extraction method. It will be very interesting to see the results got from the 6-feet diameter Blackman fan after the school is all in working order. I trust you will find your method a success, so that it may serve as a model for others.

Institution of the Smoke-Test for Drains. By W. P. BUCHAN, R.P., President of the Sanitary and Social Economy Section of the Philosophical Society of Glasgow.*

In the new edition of the *Encyclopædia Britannica*, and in the article on "Sewerage," mention is made of the use of the "Smoke-Test" for finding out, in a quick and easy manner, leakages in the drains of houses, but it is not stated there when or by whom it was introduced for that purpose. As this test is now in general use, not only in our own kingdom —where it is now referred to by Judges on the Bench, and

* Read before the Society on 13th April 1891.

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also ordered to be used in recent Acts of Parliament *—but also in foreign countries, I think it will be interesting to put on record in our *Transactions* a few historical remarks about it, more especially as it was invented by one of the Fellows of this Society.

As many of you are aware, previous to A.D. 1875 the general style of disconnecting the drains of a house from the sewer, where provision for disconnection was made, was by putting in either a large built cesspool or an old-fashioned non-ventilating trap between the house and the sewer. No provision was made, in putting these in, for allowing a current of fresh air to get into the drains, and, especially with the latter, no provision existed for seeing the state of the drain, so as to know whether or not it was serving its purpose properly. In order to improve this state of matters I, in *April* 1875, invented what has since been known as Buchan's No. 1 disconnecting and ventilating trap for drains, which trap had an opening upon its house side, which opening both allowed a current of fresh air to pass into the drain towards the house, and also permitted whatever flowed down the drain from the house to be easily seen as it dropped into the trap. Through this opening on the house side of the trap, it occurred to me that if smoke were put into the drain it would flow along the drain and go up the soil-pipes connected with it inside the house, and come out at the top like smoke out of the top of a chimney. Then, if the tops of the soil-pipe and other outlets were closed, and the doors and windows of the house all shut, I considered that if there were any leaks in the drains or soil-piping inside of the house, the action or pull of the chimneys of the house, especially those with fires on, would pull out the smoke-laden air from the drain into the atmosphere of the house, and the smoke being seen, substantial proof of the existence of leakages would be got, as well as in many cases the exact locality of the leaks demonstrated.

* In some cities and towns it is now the law that before newly-erected houses can be occupied their drains, &c., must be smoke-tested and passed as right. Many people also, for their own protection, have any house they intend to occupy smoke-tested; while it is now the practice with some to smoke-test the drainage of their houses once a year or so as a precaution, on the principle that prevention of disease is better than cure.

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Practical experiment soon proved that this idea was right,—in some cases, where the leaks in the drain were large, the smoke pouring up through the seams, &c., of the floor as if a fire existed underneath.

The first time I remember of putting the smoke into the drain of a house was at the end of April 1875, at 128 Renfield Street, Glasgow, where the first specimen of my No. 1 trap —made of sheet zinc for the nonce—was put in. The soil-pipe came down in the middle of the house, and the drain went out towards the back of the house. The trap was put on outside, about a yard or fully from the back wall of the house, and after it was fitted into its place and jointed, smoke was made to go into the drain from burning brown paper and rags. The smoke soon showed itself on the roof, coming out at the top of the ventilating pipe of the soil-pipe. This was stopped for a short time and the drain tested.

I was not pleased with the paper and rags, however, and soon hit upon using dirty or greasy cotton-waste instead, to which I added sulphur to cause a strong smell, as I found in some cases the smell would be felt before the smoke was seen. I also saw that while a house with fires on in it might be sometimes easily tested by the natural or automatic inflow of the air and smoke into its drains, this would not serve properly for a house with no fires on in it, so I immediately set about getting means for forcibly blowing the smoke into the drain. I used a small fanner bellows at first, and then coming across Bateson's fumigating machine, I afterwards used it. Some parties were at first inclined to ridicule what I was doing; but when my fellow-tradesmen discovered how quickly a house could be tested and reported upon by this means without lifting its floors, &c., they soon began to copy the plan, while I also recommended its adoption to my medical and sanitary acquaintances. I did not patent the system. In addition to the fanner and bellows smoke-testing machines worked by hand, others are now in use, the motive power of which is in one case water from one of the high-pressure cranes in the house; and in the other case, steam from a small portable steam-generator.

The amount of disease, suffering, and death which the

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introduction of the smoke-test for drains has prevented must be very great. It is now a recognised factor in the good sanitation of houses and other buildings. It is greatly to the credit of the medical profession that its members have so generally advocated its use.

On an Improved Mining Theodolite. By JOHN WHITELAW, M.E., C.E., Edinburgh.* (With Plate.)

Before bringing the particulars of this instrument before the notice of this Society, it may not be considered out of place to trace, to some extent, the history of the polarity and application of the magnetic needle to underground surveying purposes, owing to the discovery that it pointed towards the north.

The use to underground surveys of the magnetic needle placed in a box is given to Flavio Giorja, 1302, wherein the direction was marked on a series of rings of different coloured wax, the needle being placed in a sunken receptacle of a wooden box.

The next advance was a brass box sunk into the wooden box; following this, the wood box was discarded for a brass circular case.

The sights were first used in 1800, and were at first fixed by dovetail pieces and grooves. These gave place to the jointed or hinged form now generally used.

Passing on from this, we have one much used in metallic mines (Lean's); there is another by Henderson with four sights. Again, we have Hedley's, which is one of the best.

The difference of the instrument, the subject of this paper, consists in fitting the miner's dial compass, or the ordinary theodolite, with two arcs, one of which is rigidly fixed to the compass-box in the line of sight or direction of observation, and this arc has the usual graduations for taking angles of elevation or depression and reductions from the hypotenusal

* Read and illustrated by Instruments and Diagrams on 13th April 1891.

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to horizontal distances; also in attaching a large level-tube to said arc. The other of the two arcs is free to move in its bearings in a line at right angles to the line of observation. On the upper part of this moveable arc are carried the frame and sights, and telescope, which may be used instead or conjointly: the vernier for vertical angles is formed in this moveable arc.

The instrument may also be used for levelling, in same manner as is sometimes done with an ordinary theodolite, by clamping it at zero of the rigid arc; this arc is also pierced by slits, whereby the other sights can be checked. The illustration represents a 5-inch theodolite for surface or underground surveys. With a vernier working inside the compass-box—that of a mining theodolite—and without an internal vernier and the clamp, it would represent an ordinary dial with the improvements applied thereto.

The under part of frame has a groove with spring fixed to the under side of it, which makes it automatic in its action, for retaining it in whatever position it may be when an observation is being taken, and saves using the clamp.

The spirit-level L is attached by snugs for levelling the instrument and ascertaining its horizontal adjustment.

Slits are pierced in the opposite sides of the rigid arc in the same vertical plane as the sights and telescope, and these serve for ranging and checking horizontal lines. Angles of elevation and depression up to 90° can be taken without difficulty, thereby making it very suitable for connecting surface and underground surveys, and particularly for steep workings.

The arrangement of the frame with the sights admits of the compass being the same diameter as the under limb in theodolite, whereby rapidity, greater accuracy, and a more perfect check is obtained between the compass and verniers.

The verniers of the under limb are placed near to the eye and right side of the observer, which enables him to read them without changing his position, as is required by him with an ordinary theodolite.

The improved instrument may be used for taking horizontal angles, as with the mining compass or dial, by using the

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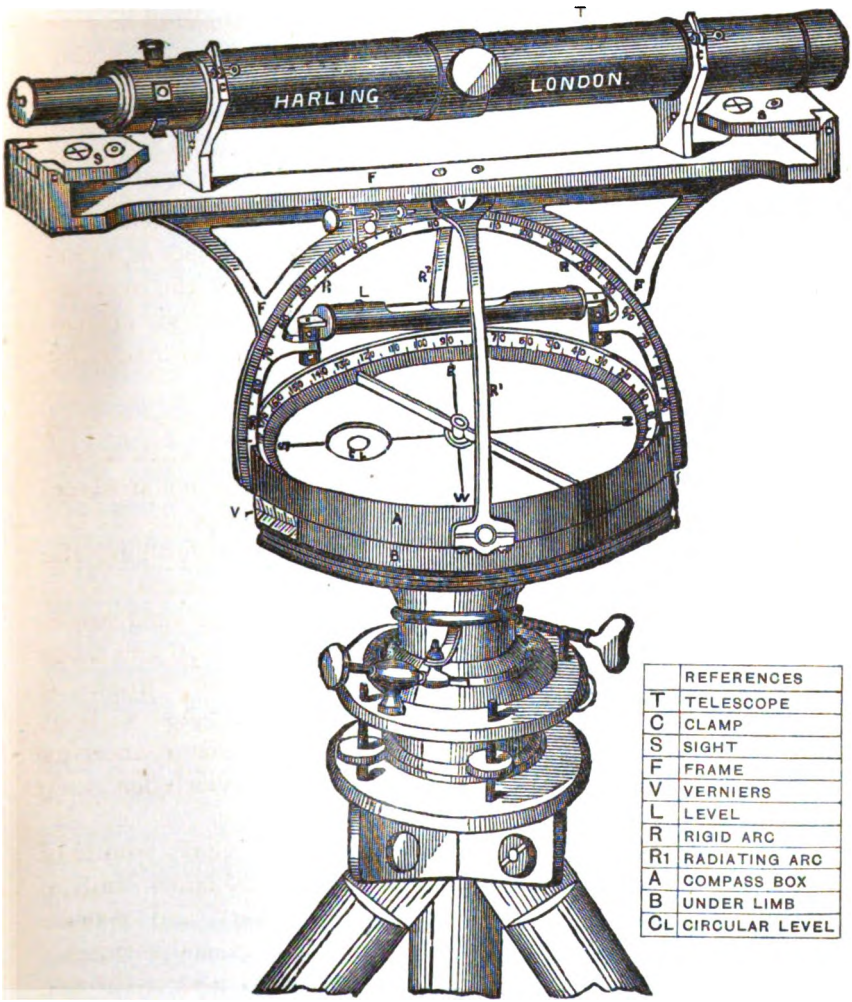
WHITELAW'S THEODOLITE.



	REFERENCES
T	TELESCOPE
C	CLAMP
S	SIGHT
F	FRAME
V	VERNIERS
L	LEVEL
R	RIGID ARC
R1	RADIATING ARC
A	COMPASS BOX
B	UNDER LIMB
CL	CIRCULAR LEVEL

John Whitelaw

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magnetic needle only, the lower limb, or inside vernier, being clamped. In this position it is also available for and especially adapted—in addition to its recognised merits for mine-surveying — for rough and closely-wooded countries where there is difficulty in obtaining long views, as it is fitted with open sights fixed below the telescope so that one or other can be used.

The improvements described are also applicable to ordinary mining or other compasses.

The improvements may be noted as consisting of—(1) In the general arrangement and construction of the parts constituting the instrument for angular measurement.

(2) Providing the compass-box for angular measurement with a rigid graduated arc fixed to the sides and over the said box, and with a moveable arc turning upon bearings on the sides of the compass-box, which carries at its top a frame provided with sights above the arc, whereby angles of elevation and depression up to 90° can be taken; and the placing of the verniers on the right of the line of sights instead of at the centre of the sides of the instrument, which obviates moving from the position for taking the bearings.

(3) The combination of a level with the rigid arc referred to in the preceding description of the drawings, &c.

(4) Forming slits in the rigid arc in the line of sights for the purpose of ranging and checking horizontal lines; also of connecting surface and underground surveys.

Clinometric Attachment to the Pocket Sextant. By J. J. CADELL, Carron Park, by Larbert.* (With Plate.)

This clinometer consists of a glass tube, of $\frac{3}{8}$ths of an inch outside diameter, bent into the form of a parallelogram 6″ long and 2″ broad. The ends of the tube are connected by a piece of india-rubber pipe, which is tied tightly over the glass so as to prevent the escape of the coloured spirits of wine with which the tube is filled half full.

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* Read and illustrated on 18th April 1891.

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The tube is mounted on a small board in such a way that when the edge is level the surfaces of the spirits in the ends of the parallelogram will stand at the centre line of the board. A small scale is placed across this line at either end of the parallelogram, so that any variation caused by expansion, contraction, or leakage of the spirits may be allowed for.

For levelling or contouring the instrument may be used as now described, the level being taken by glancing along the side of the tube, in which the two surfaces of the spirits will give a correct level.

For the purpose of fastening the level to a pocket sextant a brass bar is hinged on to the back of the board, so that when packed it lies flat along it, but when required for taking a gradient may be unfolded and clamped on to the box of the sextant, so that the line of direct vision passes along the centre line of the level, thus giving a view of the surfaces of the spirits, so that a good horizon is seen in conjunction with the fixed mirror of the sextant, which, held with the box to the right, will give the angle to any object above the horizon, and reversed will give any falling gradient.

Pedal Vice. By Louis Rottenburg, Glasgow.*

This vice differs from other parallel vices, in having the sliding bar under the bench. The plate (*P*) is bolted on to the bench top, which comes between it and the bar (into the space *b*). Fig. 1 shows the vice with one of the side-pieces (*V V*, fig. 2) removed.

The mechanism consists of a toggle-joint (*T*) and cam (*C*). The toggle-joint is rounded off at both ends, one to fit the recess of the sledge (*S*), the other to work against a corresponding recess in the casting. The two pieces of the toggle-joint articulate loosely against each other without being connected. The spring, which draws the sledge backwards and downwards, keeps the toggle in its place. The

* Read and illustrated before the Society on 23rd March 1891.

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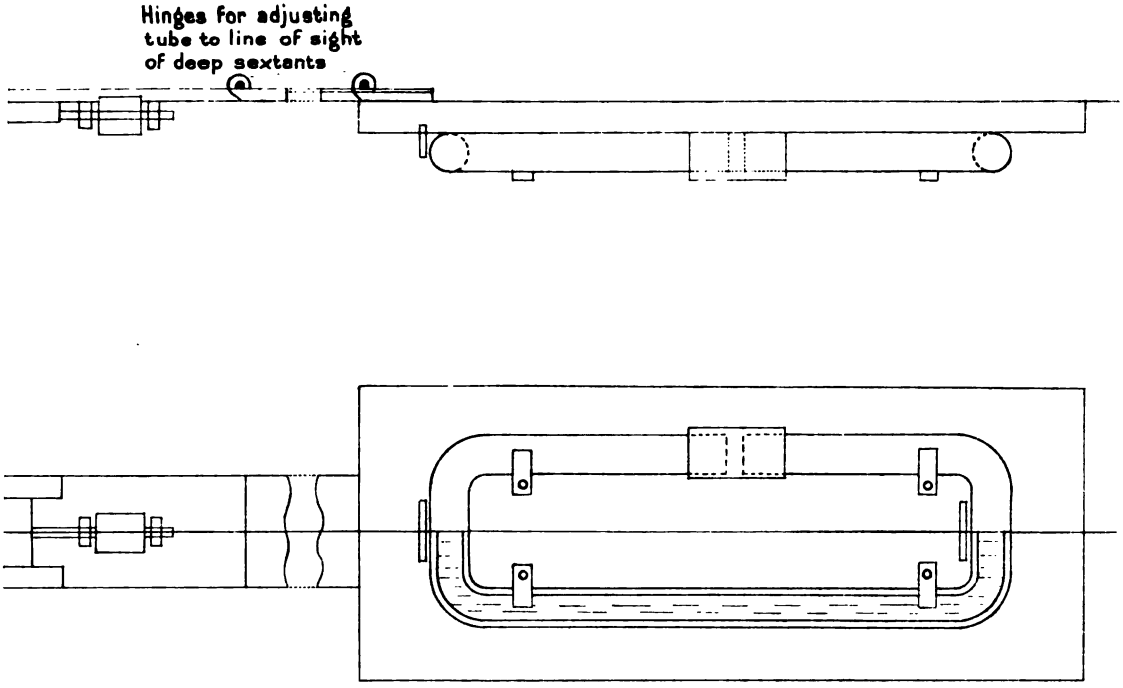
LINOMETER



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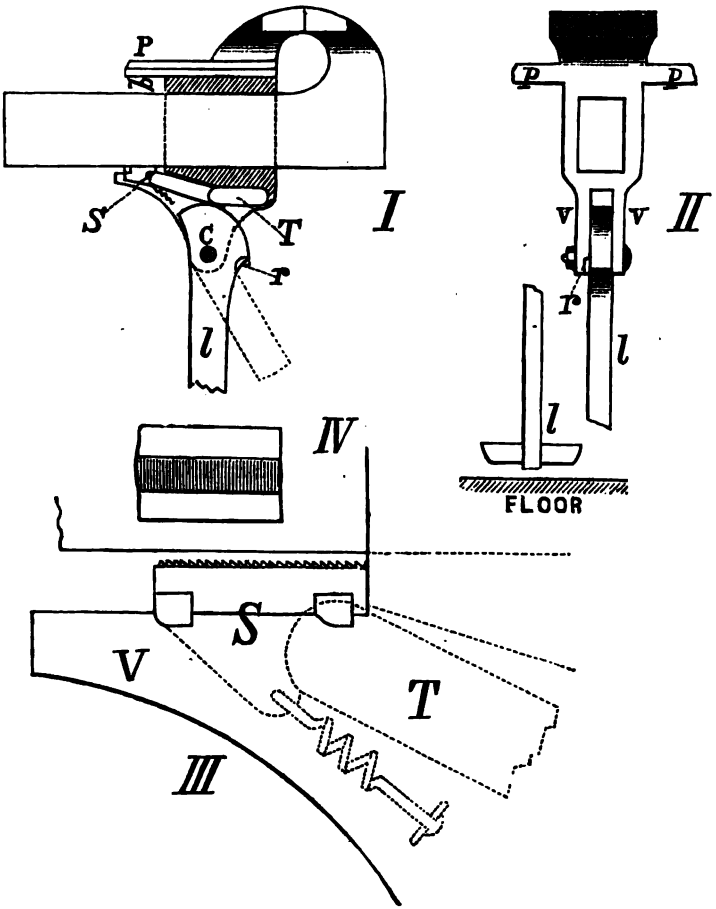
cam is continued downwards as a lever (*l*), which reaches almost to the floor, and has a cross-piece for the foot. When the lever is swung out, as shown by the dotted lines, until the stop (*r*) comes against the side-piece (*V*), the toggle-joint bends and lets the sledge slide into the recesses out of



gear (fig. 3). The sledge and under side of bar (fig. 4), have small teeth which grip into each other. When the sledge is out of gear, the jaws are adjusted to the work, and the lever tightens the grip, staying in any position by the friction of the cam.

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The advantages of this vice are:—

I. It leaves both hands free to adjust the work, which, in some instances, is difficult to do accurately with one hand, and so saves time.

II. It can be instantly set to any size of work.

The foot-rest being low down, the workman's weight is sufficient to give a very tight grip, while a tap with the toe adjusts it more delicately.

The International System of Water and Sewage Purification. By HENRY M. CADELL, Esq., of Grange, B.Sc., F.R.S.E.* (With Two Plates.)

Water Purification.

As our cities and towns continue to grow in size, the requirements of public health become ever more exacting, and it is only by adopting the most improved sanitary methods that we can hope to maintain the health and comfort of the increasing multitude around us. Sanitary science has wrought a marvellous improvement within the last quarter of a century, and the steady diminution of the death-rate, especially in connection with the zymotic diseases against which the work of sanitarians is chiefly directed, is a striking testimony to the success of their efforts.

Since a sufficient and good water supply is one of the first essentials to public health, the question of obtaining it is one of prime importance. Where good natural water is not obtainable, the only way out of the difficulty is to render such water as is available fit for domestic purposes by filtration. It has for years been recognised that a really effective filter should not only strain out all the suspended matter in the water, but should also exercise an oxidising influence on the dangerous organic matters that may be present in suspension or solution. Various filtering media have been used to fulfil these conditions, among which may be mentioned charcoal, magnetic carbide, spongy iron, and polarite.

* Read before the Society, 27th April 1891.

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Charcoal filters are found in practice to work well at first, but before long they rapidly diminish in efficiency, and finally cease altogether to remove organic matter from the water. Indeed, if still kept going, they breed a fungus, and begin to give back what has been taken from the water, so that, unless the charcoal is frequently renewed, they become much worse than useless.

To overcome the objections to charcoal, various substances, such as Spencer's "magnetic carbide" and Bischoff's "spongy iron," have been invented. Of these, the latter is decidedly the more effective, and possesses in a high degree the valuable property of condensing in its pores the oxygen of the air and employing it to destroy the noxious putrescent matters in the water. Spongy iron, however, has been found in practice to become choked up with rust in course of time, and thus to lose its valuable filtering properties entirely. It was used on a large scale at the Antwerp Water Works, but soon got choked with rust, which not only destroyed its filtering properties, but cemented the pieces together in large and useless concrete masses, which had to be removed at a loss of many thousands of pounds.*

Polarite, which is the most recently invented filtering medium, is a hard, black, porous compound, sometimes called magnetic spongy carbon, and manufactured solely by the International Water and Sewage Purification Company, 7 Victoria Street, London, who own the patents of the process by which it is made. It seems to possess all the advantages of spongy iron or charcoal without the drawbacks to these substances, as the polarite filters at the Acton Sewage Works are as active now as when they were laid down four years ago. Professor Sir H. Roscoe, F.R.S., made an investigation of the new filtrant in 1888, after it had been more than a year in use at Acton, and in his Report on the Acton Sewage Purification Works, he says, "The porous nature of the oxide which is used in the filter, its complete insolubility, and its freedom

* *Professional Papers of the Corps of Royal Engineers* (Occasional Paper Series), 1888, vol. xiv. paper viii., "The Purification of Water and Sewage by the Magnetic Spongy Carbon Process." By Chas. H. Beloe, M.I.C.E. Page 5.

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from rusting, constitute, in my opinion, its claim to be considered a valuable filtering medium. A sample of this filtering material taken at Acton gives the following results on analysis:—

Magnetic oxide of iron,	53·85
Silica,	25·50
Lime,	2·01
Alumina,	5·68
Magnesia,	7·41
Carbonaceous matters and moisture,	5·41
	100·00

Polarite filter-beds are composed of a layer of equal parts of polarite and sand, the polarite being supplied granulated to about the size of hemp seed, above which there is a layer of about 9 inches of sand to intercept all suspended matters. At Acton the filters have the following section:—

Sand,	9	inches.
Polarite 5 inches, mixed with sand 5 inches,	10	„
Sand,	6	„
Pea gravel,	4	„
4-inch drain pipes surrounded by shingle,	4	„
Total thickness,	33	„

The mud which accumulates on the upper surface of the sand requires, of course, to be scraped off periodically, and a new coating of sand put on so as to maintain its thickness, but no trouble is required to keep the polarite in order further than allowing the filter to remain dry for a few hours now and then, when the air obtains access, and it becomes thoroughly revivified and capable of carrying on its wonderful work of oxidation and destruction of noxious substances in the water. The polarite simply absorbs oxygen or ozone from the air and hands it over to the water, causing the decomposing substances in solution to be completely and rapidly oxidised, and so rendered harmless before they leave the filter.* Polarite costs about 7s. per cwt. A cubic yard

* The oxidising and deodorising power of a polarite filter was exhibited experimentally when the paper was read. A solution of sulphuretted hydrogen was passed through a small filter consisting of sand beds, with 6 inches of polarite between. After passing through the filter the strong and characteristic

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weighs about a ton, and is sufficient for rather more than 6 sq. yards of filter-bed. The usual rate of filtration through a polarite filter-bed is about 1000 gallons per sq. yard per 24 hours. Of the practical results obtained, I shall speak again when dealing with the other branch of the International System.

Sewage Disposal.

No system of water supply can be considered complete which does not embrace an equally adequate system of sewage disposal, and the question of getting the water out, is often even more troublesome than that of getting it in.

No scheme yet proposed fully satisfies all the conditions of this very pressing and perplexing problem, but advances are constantly being made, and it is of the latest advances in this direction that I wish now to speak. Before, however, going into the details of the latest methods, I shall briefly refer to some of the more important systems of sewage disposal in use at present, and point out their chief advantages or drawbacks.

For many years it was thought that sewage could be profitably disposed of by irrigation, but after long years of probation, it has been found that town sewage is not nearly such a valuable fertiliser as had been supposed, and in several cases farmers have even refused to use it when brought to their fields gratis. There are, it is true, many sewage farms and irrigation meadows still in existence, but very few of them are anything but financial failures, and the effluent water that flows from the field drains into the neighbouring streams has undergone but a slight improvement in sinking through the sodden ground. Such a system may of course be beneficial in some cases where the disposal of the sewage is a secondary object, and the farmer can use it when it is convenient, the raising of good crops being his primary intention, as in the irrigation meadows round Edinburgh. Mr

odour of rotten eggs was found to be entirely removed from the fluid, and the complete oxidation was further proved by adding a little nitrate of lead to the filtered and unfiltered solutions respectively, when the former gave a white and the latter a black precipitate.

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Santo Crimp, in his valuable book on *Sewage Disposal Works* (London, Chas. Griffin & Co., 1890), gives in chaps. x., xi., and xii. details as to the working expenses and returns of the sewage farms of Doncaster, Beddington, and Bedford, and these show that even under favourable conditions sewage farming has practically proved a financial failure in this already well-watered country.

To obviate some of the objections to ordinary sewage farming by irrigation, the system of intermittent downward filtration has been tried. In this case the sewage percolates intermittently down through specially prepared soil, and escapes by field drains, having parted with a large proportion of its suspended ingredients on the way. The ground thus fertilised yields good crops if the conditions are favourable, and the effluent is comparatively free from noxious matters. This system is in operation at Forfar, where some 24 acres are laid out for sewage treatment, and the results are said to be satisfactory. Of course, in cases where the soil is impervious and stiff, the conditions for the success of this system are awanting, and in any case a considerable area of land is required, which near a town is generally very valuable and difficult to be had for such purposes.

In the next class of sewage disposal systems, the question is treated from a chemical point of view, and the desired end is sought to be gained by the use of precipitants of various kinds. These are mixed with the sewage, and have the effect of causing the suspended and part of the dissolved matters to settle out in the form of sludge, which sinks down, while the clarified liquid is drawn off above.

Now in all such systems the success depends on (1) the amount of purification effected; (2) on the quality of the sludge produced; and (3) on the relative cost as compared with other systems. What is wanted is the cheapest way of separating the pure water from its contents, and at the same time of producing sludge that will prove of some agricultural value, and help to pay for the precipitant used in its extraction. Keeping these ends in view, many substances have been suggested as precipitants. In the old "A.B.C.," or Alum, Blood, and Clay process, these materials were added

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and caused precipitation to take place. Instead of blood, charcoal or refuse from prussiate of potash is now added where the system is in use, but the chief objection is the great quantity of sludge produced, and the excessive cost of producing it, which has led to its being abandoned at several places where the system was in operation. Another favourite precipitant used at many places is lime, to which is sometimes added black ash waste, produced abundantly in alkali works. Lime gives a clear effluent, but one which contains much organic matter in solution, is liable to undergo rapid decomposition, and when run into a stream is apt to kill the fish in it. Moreover, it produces a large quantity of sludge to be got rid of; and as lime has the power of setting free the combined ammonia, it both spoils the manurial value of the sludge and creates an intolerable nuisance by the fumes evolved. Where lime is used, the sludge produced is either sold at a merely nominal price, given away, dug into the ground, burned in a destructor, or its removal is paid for.*

To produce a good result there must be not only a clear effluent, but the effluent must be innocuous and fit to turn into any river without destroying the fish or undergoing subsequent putrefaction. Like drinking-water it must, in fact, be oxidized as much as possible, and what is wanted is some plan that will, while producing a clear effluent, provide also a cheap supply of oxygen to attack the dangerous organic matters that may not be removed with the precipitate.

There are at present, so far as I am aware, only two practical methods of obtaining a sufficient quantity of oxygen for this purpose. The first of these is the Webster process, in which electricity is used to decompose the fluid, and set free by electrolysis some of the combined oxygen in the water. This very clever application of electricity to an unusual purpose has been attended in the experimental stage by satisfactory results. The current, generated by a dynamo, is passed through the fluid by means of massive cast-iron plates for electrodes, a large number of which, arranged in series, are required to give the necessary surface. Oxygen and

* See S. Crimp., *Sewage Disposal Works*, table vi., p. 42.

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chlorine given off in the nascent state at the positive pole combine with the iron to form a salt, which acts powerfully on the sewage, and sends down a large part of the suspended and dissolved matters as a precipitate. In course of time the plates become dissolved away and require to be renewed. The system has as yet hardly passed out of its experimental stage, and though good in theory, is complicated, and looks costly in practical application, as it requires powerful steam-engines, dynamos, and skilled attendants to look after them. However, I do not wish to prophesy evil of such an ingenious invention; and the system, after more extensive experience, may be found to give better and cheaper results than it has as yet afforded.

The second practical method is one about which there can no longer be any dubiety, as it has been sufficiently well tried to warrant a clear and satisfactory conclusion being formed as to its working and merits; and to a consideration of this system, which is more particularly the subject of the present communication, I shall now devote the remainder of the paper.

The International System of Sewage Purification.

After one of the most exhaustive enquiries that have been yet made as to the best method of sewage disposal, the Royal Commissioners on Metropolitan Sewage Discharge, who were appointed in June 1882, unanimously recommend in their Report, dated 27th November 1884, the system of precipitation and filtration. Precipitation and filtration had been used together or separately, as we have seen, with more or less indifferent results, and the great difficulty was to get the right materials to effect both these objects at the minimum of expense and maximum of efficiency. Happening to hear, while on a visit to London in 1888, of a new process, invented to meet the recommendations of the Commissioners, I paid a visit, in rather an incredulous mood, to Acton, a western suburb of the metropolis, where the "International System" had been introduced more than a year previously to supersede the old A.B.C. process, condemned on account of its inefficiency and cost. I was both

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pleased and astonished at what I saw, and on making enquiries as to its practical working, quickly changed my opinion as to the merits of the new process. Three years have passed, and I have had sundry opportunities of extending my investigations and watching its operation, and the more I have seen the more I am convinced that from whatever aspect it is viewed, the "International" is by far the best method of sewage purification that has yet been devised.

The system is characterised, not by any great novelty in its mechanical principles, but by the nature of the materials it employs in the purification of the sewage.

The precipitant known commercially as "Ferozone" is a black, magnetic preparation containing salts of iron, alumina, and magnesia, as well as magnetic oxide of iron in a very spongy and absorbent condition, obtained as a bye-product in the manufacture of the polarite of which I have already spoken. The following analysis by Professor Sir H. Roscoe gives the composition of ferozone used at the Acton Sewage Works:—

Soluble constituents—	
Ferrous sulphate,	26·64
Aluminium sulphate,	2·19
Calcium sulphate,	3·30
Magnesium sulphate,	5·17
Combined water,	8·20
Moisture,	24·14
Insoluble constituents—	
Silica,	11·35
Magnetic oxide of iron,	19·01
	100·00

From this analysis it will be seen that ferrous sulphate, which acts as a powerful chemical disinfectant as well as a precipitant, enters largely into the composition of ferozone. The soluble salts of alumina, lime, and magnesia also assist in the decolorisation and precipitation of the sewage. The insoluble portion, consisting mainly of powdered polarite, serves to oxidize the putrescible matter, and to accelerate by

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its weight the subsidence of the precipitate. The rapidity of precipitation is hardly less important than its completeness when large volumes of sewage have to be dealt with, as a speedy separation of the sludge from the supernatant fluid enables a much greater quantity to be treated in the same tanks than could be disposed of with a slowly working precipitant. The magnetic spongy iron has this further advantage, that it tends by its oxidizing power to keep the sludge sweet during subsequent disposal, either when being pressed or dried for manurial purposes. This is an important consideration, as it prevents the proximity of the sewage works from being a public nuisance, such as is the case where lime enters into the composition of the precipitant. The absence of all disagreeable odour is not the least of the merits which are claimed by the International System, and in the many visits I have paid to works on this system I have been much pleased and struck by this circumstance.

The value of sewage as a fertilizer has, as we have seen, not been found so great as was formerly supposed, and this is one reason why sewage farming has been often abandoned. Sewage, it must be remembered, is a very indefinite term, and is very variable in composition. It is simply a name for all the liquid refuse of a populous place, and may contain large quantities of chemical or other ingredients that have no agricultural value whatever. It is like Police manure, which often consists as much of broken dishes, paper, and tin cans, for which the farmer has no use, as of good ashes and fertilizing matters capable of adding to the productiveness of the ground. Whatever the value of the manure from sewage may be, it is clearly the best principle in any system of precipitation to aim at turning this value to the best account. There is no use of spending money, as in the A.B.C. process, in practically putting in the fertilizer as a precipitant, to take it out again along with the sediment from the sewage. Again, it is an equally wrong principle to leave out of view altogether this possible source of profit, as is done in the lime process, which spoils the sludge as a fertilizer. What seems to be wanted is, a precipitant that will throw down any valuable manure that the sewage may con-

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tain, and produce a concentrated fertilizer that will find a market and help to pay the cost of its production. The sludge should be as small in quantity as is consistent with efficient purification, because, if it has any value at all, it is thus most concentrated and most valuable, and if it is worthless, then there is always the smallest quantity to get rid of. So far as my observations go, the sludge produced by ferozone satisfies these conditions as well as, or better than, any other kind I have heard of. When pressed and dried at Acton it was selling as a garden fertilizer for 30s. per ton at the time of my visit three years ago, but I do not mean to assert that if large quantities were thrown on the market anything like this sum could be obtained from farmers generally.

As to the cost of ferozone, it is found in practice that from 5 to 10 grains are required to precipitate every gallon of sewage, the quantity varying according to the amount of impurity in the fluid. As ferozone costs about 3s. per cwt., if we take say 8 grains as the average quantity used per gallon, we find that it costs about 30s. 7¼d. to precipitate 1,000,000 gallons, or, to reduce the scale, for something less than 3¾d., 10,000 gallons of sewage can be effectually precipitated. In small works, such as at Larbert, where it is not worth while making special arrangements for completely mixing the precipitant, the cost is considerably greater, as a certain proportion of the ferozone passes undissolved into the sludge, and so is lost. But in proportion to the results, which, as we shall see, are afforded by this system, the expense of the ferozone is not, I think, at all exorbitant.

After remaining undisturbed for a couple of hours, the ferozoned sewage, which is now nearly clear on the surface, is run on to the polarite filter-beds, while the sludge sinks down, and when all the clarified supernatant fluid has been drawn off, is allowed to escape by a separate outlet into the sludge-well. Although the fluid from the tanks is only slightly opalescent, and contains almost no suspended matter, a thin film of mud accumulates on the filter-beds in course of time, and to ensure regular working this needs to be scraped off periodically, and a fresh skin of sand put on

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to replace it. Beyond this the filters require no further attention.*

Last summer the Stirling District Lunacy Board, like many other bodies in charge of public property, was in perplexity as to the old question of sewage disposal. The sewage of the Stirling District Asylum at Larbert was being used for irrigation, and had to be run into a tank, from which it was pumped up by steam, and discharged on to the land and garden belonging to that institution by means of pipes radiating outwards from the engine. This process was, after working for many years, found to be very unsatisfactory, chiefly for these reasons.

1. The soil, being chiefly stiff, was unsuited for irrigation, and consequently no benefit was derived from the sewage as a manure.

2. The sewage, after a time, percolated through the ground, and finding its way into the field drains contaminated the water in the adjoining streams, which led to the Board being threatened with actions of damages from neighbouring proprietors.

3. The Medical Superintendent—Dr Macpherson—thought that in the non-absorbent soil at the Asylum, it was questionable if the practice was healthy.

Such was the state of matters last spring when the new Board, representing the County Councils of the Stirling District, appeared on the scene. After giving the matter serious consideration, the Board resolved, on my recommendation, to give the International System a trial, as we saw no better way out of our difficulties. Fortunately, the Asylum is situated high enough to allow the tanks and filters to work by gravitation, so that all need of pumping

* The process was illustrated experimentally when the paper was read. Samples of fresh and fœtid sewage were, after being exhibited to the Society, mixed with a small quantity of ferozone, and in less than half an hour a thick precipitate had settled down in each glass, leaving an opalescent fluid above. This was then poured on to filters containing 6 inches of granulated polarite between sand layers, and a clear odourless and colourless fluid came through, which, unlike the original fluid, did not turn brown when mixed with permanganate of potash, thus showing the oxidation to have been very perfect, and the rapidity of the purification very great.

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is avoided. The necessary works, begun last autumn,* consist in the first place of the main outfall sewer leading from the Asylum and its offices. At the mouth of this sewer is a rectangular manhole, used as the ferozone chamber, in which is placed a galvanised wire basket containing the precipitant. As the sewage flows quietly through the chamber it carries off a part of the ferozone, and the basket requires to be replenished about twice a day. After being thus charged with the black powder the fluid passes along the "mixing race," a rectangular wooden rone with bafflers placed in it, like the bars in a salmon ladder, which cause the sewage to rush from side to side of the channel and become more thoroughly incorporated with the ferozone than could be effected by a straight run. The inclination of the mixing race is greater than that of the sewer, so as to give greater velocity to the fluid, and prevent it from depositing the precipitate before reaching the tanks. The distance between the ferozone chamber and the tanks is about 70 yards, and at the lower end of the race there is a Y-shaped inlet trough with a hinged sluice at the fork, to allow the sewage to be easily turned into either tank (see fig. 1). There are two tanks, each of which is 30 ft. long, 15 ft. wide, and 6 ft. deep. A floating shoot with cross ribs is provided at the inlet and attached at one end by a hinge to the wall just below it. The ferozoned sewage thus runs down a short stair, and becomes partially aerated as it enters the tank. As the tank fills, the free end of the trough rises till it floats horizontally on the water. The aeration of the sewage in this way is important, as it assists oxidation and promotes the efficacy of the ferozone.

The floor of each tank, as shown in the accompanying plan and sections, slopes towards a gutter running diagonally between the opposite corners. Both gutters converge and slope towards the corner below the inlet, so that the sludge may accumulate at this point as much as possible. There is a valve outside the wall of the tanks opposite the lower end of each gutter, which can be opened after the clarified sewage

* The works were constructed from plans prepared by Messrs A. & W. Black, C.E., Falkirk, Architects to the Stirling District Lunacy Board.

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has all been drawn off, to allow of the sludge being run out into the sludge-well, shown on the drawing below the inlet channels.

The sludge-well in course of time becomes filled with the precipitate, and as there is always some water discharged along with it this rises to the surface, leaving the thick black mud below. This surface water is drawn off by a hand pump, with a floating suction-pipe, and discharged into the tanks for treatment over again. The sludge below is then taken out by a chain pump, and it is intended to mix it with dry ashes and use it for manure, as the quantity produced is too small for special treatment. As yet a remarkably small quantity of sludge, in comparison to the volume of sewage, has been produced.

After being allowed to stand and settle for a couple of hours, the clarified sewage is drawn off gradually by means of a floating arm, with a mouth which constantly remains a few inches below the surface of the water until the tank is emptied. The lower end of the arm is fitted by means of a watertight joint or stuffing box to a pipe which opens on to the filter-beds. To prevent the gushing water from stirring up the filtering materials, an iron trough is sunk into the top layer of sand opposite the inlet pipe, and the water first fills it, and then quietly overflows on to the filtering surface.

The filter-beds, as well as the tanks and sludge-well, are made of concrete, coated with smooth cement. Each filter has a superficial area of about 20 square yards, so that with only one filter in operation at a time there is provision for filtering 20,000 gallons daily, which is more than equal to the present requirements of the Asylum.

The materials in the filters are arranged as follows:—

	Feet.	Inches.
Sand, ...	0	9
Polarite and sand, ...	0	12
Sand, ...	0	4
Granite chips (3 inches small on 3 inches large),	0	6
Broken stones surrounding 4-inch drain pipes,	0	5
Total thickness of filter-bed, .	3	0

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The arrangement of the drains is seen on the plan. The main drain crosses between the filter-beds, so that if necessary water can be made to run down through one filter and up through the other, in order to wash the film of mud from the surface of the sand in the latter. The outfall pipes from the filters open into an inspection chamber, lined with white enamelled tiles, to allow the effluent to be examined ere it finally flows off into the burn.

After the works had been about a month in operation, specimens of the crude sewage, ferozoned sewage from the tanks, and filtered effluent were sent to Professor Ivison Macadam, F.R.S.E., F.C.S., for analysis, and the results he obtained show that the Board have every reason to be satisfied with the adoption of the International System. The sample of sewage submitted for analysis before passing into the ferozone chamber was found to contain an abnormally large proportion of putrescible organic matter, so that the test of the efficacy of the system was a very severe one. Ordinary town sewage contains on the average about 120 parts of suspended and dissolved matters in every 100,000 parts of water, but the Asylum sewage was found to have no less than 461·77 parts of solid matter in suspension and solution.

The analysis of the clarified ferozoned sewage before entering the filters shows the efficacy of this system of precipitation. During this first stage of the process the total solid matter in suspension and solution had fallen from 461·77 to 41·61 parts per 100,000, *i.e.*, 90 per cent. of the impurities had been removed, and of the original 400·51 parts of suspended matter only 2·91 were left. The liquid had passed from a gross and offensive fluid to a slightly opalescent one, with a very faint fœtid smell, and the organic matter had been reduced from 31 to 10 parts. The saline matter, however, was scarcely diminished in quantity, as it was only reduced from 30 to 28½ parts; but this was partly to be accounted for by some of the ferozone having entered into solution. The greatest and most beneficial change was, however, the reduction in the ammonia from 6·22 to 0·618 parts. This reduction was the more important when it was noticed

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that the albuminoid or putrescent ammonia had fallen in quantity from 3·414 to 0·192 part—a diminution of 94½ per cent.

After passage through the Polarite filter a further improvement was observable, for the liquid was now devoid of colour and smell, and contained practically no suspended matter. The salts, it is true, had undergone no reduction, but there was a further and considerable disappearance of organic matter, viz., 2½ parts from suspension and 3 parts from solution. This was perhaps best shown by the relative amounts of oxygen required to oxidize the organic matter in the liquid; for while the crude sewage required 175 parts of oxygen, the purified effluent needed only 3½ parts to oxidize it completely. The total ammonia was further reduced to less than half the quantity in the water from the precipitation tank, and during the whole process 98⅓ per cent. of albuminoid and 91½ per cent. of saline ammonia had been removed from the original fluid.

The results of the analysis are tabulated on next page. In his report, Professor Ivison Macadam states that these results are much better than any he has previously obtained, and indeed are better than any published results he is aware of. "The Larbert effluent is not," he says, "of course, pure water, but I am satisfied that the system of purification now adopted is the best available. It converts the liquid from a grossly polluting and extremely offensive body into a clear water containing some salts, but devoid of substances which can enter into a state of active putrescence."

Dr Macpherson and I tested with permanganate of potash the clear and sparkling effluent from the filters, and the water of the streamlet into which it flows, and we found that instead of polluting the burn any longer, the purified sewage produces a marked improvement in the quality of its water.

I have dwelt at some length on the Larbert Sewage Works, not because they are either larger or particularly complete, but because the Stirling District Lunacy Board is the first public body which has been bold enough to introduce this new system into Scotland, and Larbert is the only

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place in this part of the United Kingdom where it can as yet be seen in successful operation.*

Table A. (*parts per* 100,000).

	Crude Sewage.	Ferozoned Sewage.	Filter Effluent.
In suspension—			
Saline matter, . . .	161·87	0·18	0·21
Organic and volatile matter,	238·64	2·73	0·16
Total solid matter, . .	400·51	2·91	0·37
In solution—			
Saline matter, . . .	30·17	28·40	27·44
Organic and volatile matter,	31·09	10·30	7·21
Total solid matter in solution,	61·26	38·70	34·65
In solution and suspension, .	461·77	41·61	35·02
Total chlorine, . . .	5·65	5·97	5·97
=Chloride of sodium, . .	9·31	9·83	9·83
Oxygen consumed (Edinburgh water=0·41),	175·10	9·90	3·50
Nitrogen as nitrates, . .	0·003	0·004	0·021

Table B. (*parts per* 100,000).

	Crude Sewage.	Ferozoned Sewage.	Filter Effluent.
In suspension—			
Saline ammonia, . . .	2·104	0·015	0·001
Albuminoid ammonia, .	3·201	0·005	0·002
In solution—			
Saline ammonia, . .	0·702	0·411	0·240
Albuminoid ammonia, .	0·213	0·187	0·054
In solution and suspension—			
Saline ammonia, . .	2·806	0·426	0·241
Albuminoid ammonia, .	3·414	0·192	0·056
Odour of sample, . . .	Very offensive.	Slightly fœtid.	None.
Colour of sample, . .	Very gross, much suspended matter.	Slightly opaque.	None.

* The system has been already adopted at Castle-Douglas, and I understand that the works, which were begun some months ago, will very soon be ready for a start.

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The International System can be used equally well by the smallest as well as the largest communities. At Acton the works are designed to meet the requirements of a population of some 20,000, and several of the large cities in England are making arrangements to follow the example of the smaller towns in which the system has proved a success. The following abstract of a report made last summer by Professor E. Frankland, F.R.S., to Major Tulloch, the chief engineering inspector of the Local Government Board, will show the high opinion which this eminent authority has formed, after investigating the working of the International System at Acton:—

"These results show that the raw sewage contained a very large proportion of highly polluting suspended matter and an unusually large amount of foul organic matter in solution; and further, that the effluents from the subsidence tank and filter were derived from sewage of about equal polluting power as regards dissolved organic matter.

"In the subsidence tank the suspended matter was reduced from 240·80 parts per 100,000 of raw sewage to 5·92 parts per 100,000 of tank effluent, whilst the effluent from the filter was free from suspended matter. It was clear and transparent. This is a satisfactory result.

"The effect upon the dissolved organic matter in the subsidence tank is very remarkable; its amount being reduced to little more than one-tenth of that present in the original sewage.

"In its subsequent passage through the filter, the dissolved organic matter is still further reduced to nearly one-sixteenth of that present in the original sewage. It is now in a state of purity greatly exceeding that prescribed by the standards of the Rivers Pollution Commissioners.

"No chemical process of purifying sewage has ever, in my experience, approached this in efficacy; and if the results obtained at Acton can be accomplished in other places, a most important advance will be made in the purification of the sewage of towns.

"I need scarcely add that the effluent from the filter is not only clear but inodorous and inoffensive. It is of course not fit for dietetic purposes; but it may be admitted in large volumes into running water without creating any nuisance."

Mr J. Carter Bell, A.R.S.M., F.I.C., &c., County Analyst for Chester, Salford, &c., who has been engaged in making experiments on various systems, read an important paper before the Manchester Section of the Society of Chemical Industry on 7th November 1890, on the results of his investigations, and spoke of the International System in the following terms:—

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"The International Water and Sewage Purification Company's method consists in adding to the sewage a substance called ferozone, and then allowing the treated sewage to settle in tanks. From these tanks it is passed on to the filter-beds, which are made up of sand and polarite, and it certainly was very surprising to see a liquid running from the filter as clear as spring water; and when one considers the foul nature of the Salford sewage, one cannot but be impressed with such results. The question presented itself to his mind: 'Would not a sand filter answer as well as the polarite?' To test this he had two filters fitted up in his garden, one was polarite and the other sand. Gallons of sewage, after being treated with ferozone, were passed through the two filters. The effluents were compared and analysed. At first the sand produced a good effluent, reducing the albuminoid ammonia by about 70 per cent., but soon the effluent began to be cloudy and the purification power was reduced; the polarite filter gave clear and bright effluents, and when the filter was given sufficient rest, the albuminoid ammonia was reduced to a minimum; in one instance it was as low as ·02 in the 100,000. This is actually as good as many well waters in country places. Mr Carter Bell said he was at first rather sceptical as to the length of time these polarite filters could last, but he had paid a visit to Acton and seen the filter-beds which had been in operation nearly four years, and the effluent which was flowing from the filter-beds was as bright and clear as those which were obtained from the filters in Salford, and from the experimental filters fitted up under his own superintendence. He said that he fully confirmed what Sir Henry Roscoe had reported upon this process. Mr Carter Bell said that he had taken samples from the Irwell, Irk, and Medlock, three of the foulest rivers in England; had passed these samples through filters of polarite, and had produced, comparatively speaking, pure water. The Irk and the Medlock are rather worse than ordinary Salford sewage, and therefore the test upon the polarite was very severe. But when ordinary well waters, which are not fit for domestic use, are passed through filters of polarite, they are immediately purified and made fit for ordinary daily use. Therefore, judging from his many experiments, he thought Local Boards, who had reason to doubt the purity of their water supply, could not do better than pass such water through filters of polarite."

Mr Carter Bell has had occasion also to analyse the crude sewage and the effluent at Acton, and the following is his report on the analysis:—

"I enclose the analysis of the crude sewage and also of the effluent. These samples I took myself from the Acton Sewage Works, on Saturday, 30th August 1890.

	Parts per 100,000. Sewage.	Effluent.
"Total solid matter at 212° F., . . .	361	76
Suspended matter, ...	306	Nil
Do. mineral matter, . . .	190	„
Do. organic do., . . .	116	„

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	Parts per 100,000. Sewage.	Effluent.
Total solids in solution,	55	76
Do. mineral do.,	35	49
Do. organic do.,	20	27
Chlorine,	5	6
Oxygen required for 15 minutes,	1·28	·04
Do. do. 3 hours,	2·55	·24
Free ammonia,	6·40	·22
Albuminoid ammonia,	·70	·035

"The effluent was flowing exactly like clear spring water, and when the sample was put into the bottle there was not the slightest odour of any kind, and it would have been impossible for any one to have said, judging by the appearance, that it was not good drinking water. The analysis also shows that the reduction of the putrescent matter has been very great, and that such an effluent as this may be run into any stream with perfect safety. I am surprised to find that after more than three years working the filter-beds can produce such a good effluent.

"(Signed) J. Carter Bell, A.R.S.M., F.I.C., &c.
County Analyst for Chester, Salford, &c."

Two years ago the International System was introduced at Hendon, a district on the north of London with a population of 10,500, to supersede the lime process, which had proved a complete failure. The existing precipitation tanks, &c., were used for the ferozone, and polarite filters were constructed at the outfall, instead of the earth filter-beds intended to purify the lime effluents. The result of the change has been highly satisfactory. I visited the Hendon works in the beginning of this month, and was very pleased at their success.

The great superiority of the International to the Lime Precipitation System is well shown by the following analysis by Dr Angell of the Hendon effluent, produced in either process :—

	Lime Process. Collected 6th March 1889.	International Process. Collected 15th April 1889.
Free ammonia,	4·75 (parts per 100,000)	0·0312
Albuminoid ammonia,	1·50 „	0·0080
Chlorine,	8·60 „	8·6000
Solids in suspension,	2·46 „	None.
Residue,	Filthy „	Clean.
Residue on ignition gave off,	Foul sewage odour „	No bad odour.
Physical properties of effluent,	Very turbid, stinking, foul odour „	Slightly opalescent.

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As to the quantity of sludge produced, and the cost of producing it at Acton, the International System produces, from 1,000,000 gallons of crude sewage, on the average about 26 tons of moist sludge. When the water is pressed out this quantity is reduced to 7 tons of sewage cake, which again is equal to 3 tons of dried sewage manure sold as a fertiliser at 30s. per ton. The ferozone cost in 1888 about £1 per 1,000,000 gallons, so that were all the sewage manure disposed of at only 10s. per ton, it would pay the expense of the precipitant. The population of Acton is about 7000, and the annual cost, exclusive of pumping the sewage, and pressing the sludge, is £226, 10s., which includes £70, 10s. for 27 tons of ferozone, and £156 for labour of attending to filter-beds, tanks and sludge at £3 per week.

Mr Santo Crimp, in his book on *Sewage Disposal Works*, at p. 207, gives an analysis by D. Angell, of the International Process Sewage Manure, from Hendon, collected 9th May 1889, from average daily samples produced during a period of two months, as follows:—

"*Analysis of Sewage Sludge from Hendon, air dried.*

	Per Cent.
"Moisture,	12·62
Organic matter,	46·60
Oxide of iron,	3·60
Alumina,	2·96
Phosphate of alumina,	2·21
Magnesia,	None
Potash,	0·29
Sand and clay,	29·20
Sulphuric acid (SO_3),	1·46
	98·94
Ammonia,	2·28

"This sludge is in a fine uniform state of division, and is of good quality in manurial properties. (Signed) ARTHUR ANGELL, Ph.D., F.I.C., *Public Analyst.*

"The 2·28 per cent. of ammonia, at present market value of 8d. per lb., would be worth about 34s. per ton of sludge dried to 12½ per cent. moisture; the quantity of such dried

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sludge obtained from one million gallons is estimated at 16 tons, and the value £27, 4s. for ammonia exclusive of the value of the phosphates, potash, &c."

If each million gallons could be relied on to produce manure to the value of £27, as Dr Angell estimates, then sewage treatment would be revolutionised and the problem solved completely. But sewage is a very variable quantity, and although in some cases this result might be obtained, yet I should not like to hold out any great hopes in these times of agricultural depression of reaping large profits from the sale of the sewage manure produced either on the International or any other system.

In conclusion, the advantages of the International System may, I think, be summed up as follows:—

1. A remarkably pure effluent is produced.
2. The process is very simple and easily worked.
3. It is applicable on any scale.
4. It causes no public nuisance.
5. The minimum of area is required for the works.
6. The smallest quantity of sludge is produced.
7. The maximum value of the manure is obtained.
8. The working and first cost of the works are small.

I cannot but think that it is to this system, or to something like it, that we must look for the successful disposal of the increasing volume of foul waters from our great cities and rural towns. Were the sewage of Glasgow collected at suitable points and treated in this way, the Clyde might again become a clear and wholesome flood. The south side of Edinburgh, again, might have all its sewage discharged as clear as crystal into the Powburn, as is done into the Thames at Acton. It seems a pity to solve the problem by diverting the natural drainage of the land into sewers, and pay compensation to millers for drying up the sources of our urban streams, when means have been invented of producing clean water at once, quite pure enough to flow into any river. The cost of carrying out the International System is much less than that of laying miles of expensive sewers, and the result is much better, for the sewers simply

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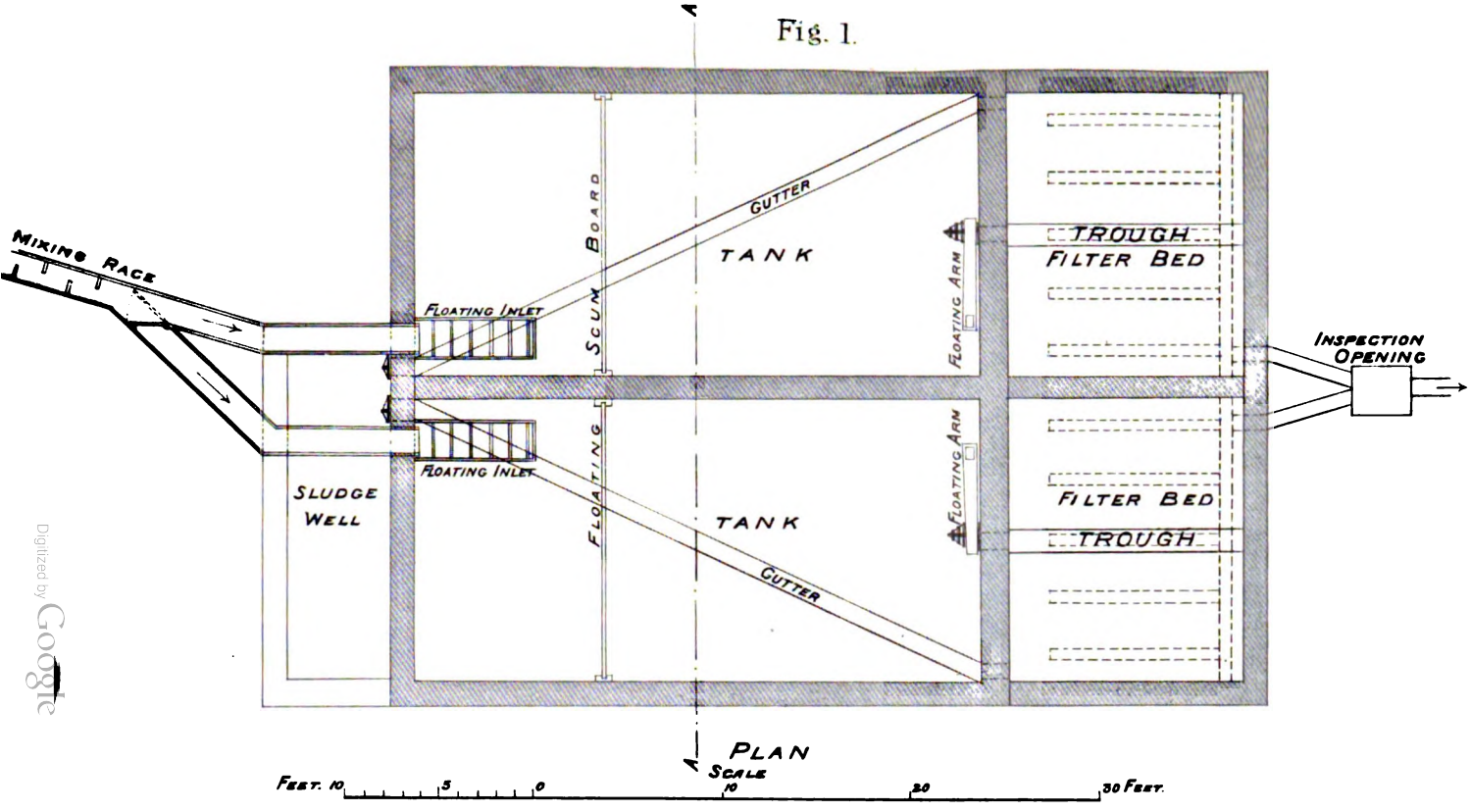
SEWAGE WORKS AT STIRLING DISTRICT ASYLUM, LARBERT, 1891.

Fig. 1.



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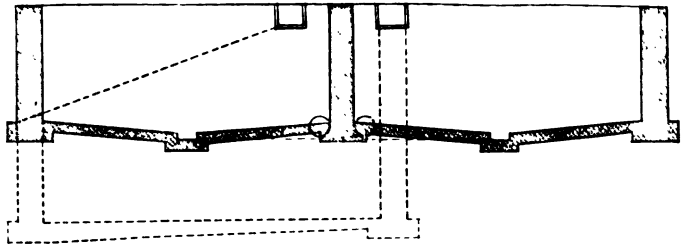
SEWAGE WORKS AT STIRLING DISTRICT ASYLUM, LARBERT, 1891.

Fig. 2.



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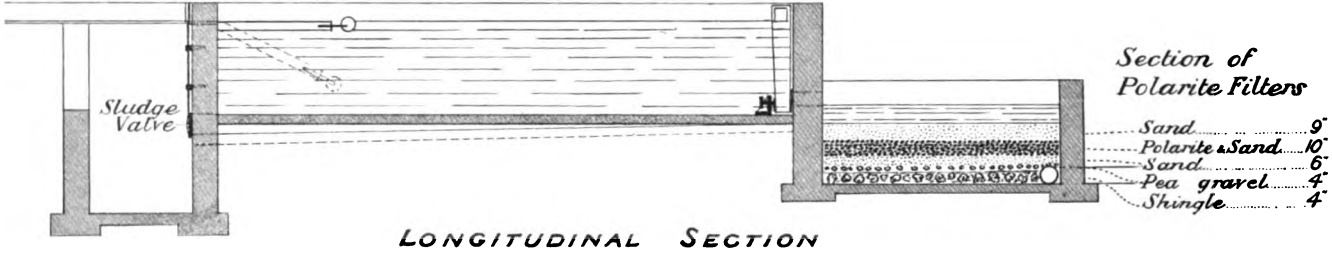

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remove the nuisance to a distance and pollute the sea at their mouth, while the International System removes the nuisance altogether at its source; or, in other words, prevents the nuisance ever being formed. So soon as the foul water leaves the houses it is caught up, purified and run into the streams, to find its way to the sea by the natural drainage channels of the country. Were this system adopted, and the sewage of our towns concentrated at convenient places, purified and discharged into the nearest stream, the sludge being sold to the neighbouring farmers or market gardeners, a very great advance in practical sanitation would be made. Not only this, however: the land along our urban streams would increase in value, fish would again return to their old haunts, and life in the vicinity generally would be more worth living. There are, of course, some kinds of sewage, such as esparto liquor from paper mills, which, for chemical reasons, may not be thus capable of purification, but I think I have said enough to show that, as a means of purifying ordinary domestic sewage, which forms, as a rule, the great bulk of the liquid refuse of our cities, the International System has proved one of the most valuable aids to practical sanitation that have been invented within recent years.

A Description and Comparison of the Methods of Electric Lighting at present in Use in London. By ALEXANDER B. W. KENNEDY, F.R.S., M. Inst. C.E., &c., Emeritus Professor of Engineering in University College, London.*

The vigorous and successful work done during the last two or three years by the various companies which are supplying electricity under Acts of Parliament has now brought the question of lighting our houses by electricity out from the region of hoping and scheming into that of practical—and already even financial—success. Nowhere has this been the case more than in London, where the whole of the metropolitan

* Read before the Society on 11th May 1891.

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area has been parcelled out to various companies,—generally two companies, having different systems of distribution, to each area,—most of which are now in active work. Not only to electricians, therefore, but still more specially to those who are still in the outer darkness which precedes the coming of electric light, the present condition of this matter in London may be specially interesting. This is, of course, the reason for my presence here this evening. It happens that I have myself designed some of the largest distributing systems and central stations in London, stations which, I am happy to say, are already in very successful operation, and therefore I may claim, at least, the advantage of a practical knowledge of the subject on which I have to speak to you. Perhaps I may say also, although this is a purely personal matter, that it gives me special pleasure to speak on this subject in a city of which I was so long a citizen, and with which I have so many pleasant associations, as Edinburgh.

I will confess, at the outset, that I always feel a lecture of this kind to be a peculiarly difficult task. Nothing is easier than to talk technically to technical men, but I have been warned by your Secretary that the members of the R.S.S.A. are by no means all technical men, and that I must not at all assume even an elementary acquaintance with electrical science on the part of all my hearers. At the same time, I cannot be far wrong in assuming that some of my audience have an intimate acquaintance with the theoretical part of the matter at least, if not with the special details of what may be called *metropolitan electricity*. Under these trying conditions I can only express a hope that those of my audience who are electricians, or engineers, or both, will bear with me while I am dealing with matters of great familiarity to them, and that those who look on the subject simply from the point of view of good citizens who would like to use electric light if they could get it, will pardon me if at times I am somewhat more technical than interesting or instructive to them.

To begin at the beginning. There are now at work in London a number of electrical companies, each in its own district, under its own special Act of Parliament, and each

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performing its duties in its own way, subject to the general control of the Board of Trade and the Local Authorities. The function of each of these supply companies is that simply of supplying electric current as the gas companies supply gas. They build "central stations" in which electric energy is generated, and lay "mains" along the streets, past the fronts of the houses, by which this energy is distributed to consumers. The mains are, of course, of copper, either in the form of insulated cable or of naked strip carried on insulators in conduits of some kind. Any person who wishes to use the electric light has his house "wired" for the purpose by one of the many contractors who undertake such work, and then has this internal wiring connected up to the company's mains, just as the internal gas pipes of a house are connected with the street gas mains. The current used in the house is measured and paid for by meter, just as gas is, and the accuracy of the electricity meter—if not yet all that it ought to be—is at least probably greater than that of the ordinary domestic gas meter.

There are certain points about the generation of electricity in central stations which are common to all the systems in use in London and elsewhere, and which it may therefore be convenient to mention first. They lie at the root of the whole matter, and some understanding of them is at first essential for following the more detailed matters of which I have to speak later on. After what I have just said I will not therefore further apologise for dealing with points, at the outset, which must be "household words" to some of my audience.

First let me remind you that the whole of the electric energy generated is obtained primarily by the combustion of coal. The electric energy is just as much a transformed form of heat energy as the mechanical energy used in work-shops. Therefore, electric lighting, although it will avoid the blackening of walls and ceilings, is not to be regarded as a smoke preventer, as I have sometimes found to be popularly the case. In every central station for the generation of electric energy, coal is burnt in the usual way under boilers. In these boilers steam is generated and is in its turn employed to drive steam-engines, also in the usual way. The *heat* energy is thus, in

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the first instance, transformed into *mechanical* energy,—electricity comes in in the next process only. The steam-engine is used to drive a dynamo-electric machine, usually called shortly a "dynamo," and in this way a part of its mechanical energy is finally transformed into electrical energy. The dynamo may be looked at as the *pump* which pumps the electric current along the solid copper of the mains,* just as the pumping engine at water-works pumps the water through the pipes.

It is well that you should have some clear notion of what this most important piece of apparatus—the "dynamo"—is, and does. By far the best elementary illustration of the working of a dynamo-machine which I have seen is one given last year in a lecture by Mr Preece, and as you may not know it I shall not hesitate to pass it on to you. It is a well-known fact in electricity that if a wire of conducting material, such as copper, be moved across the space between the poles of a magnet, what we call a *current of electricity* traverses that wire for the instant. A dynamo in its simplest form is a machine consisting of a very powerful electro-magnet or magnets, between the poles of which a large cylinder of wires or bars called an *armature* is caused to revolve rapidly by a steam-engine. Twice or oftener in every revolution, therefore, as a consequence of this forced motion of the conducting wires across the magnetic "field," a current passes through each wire, and these currents, collected and directed by special apparatus, are the currents which traverse the mains and are utilised for lighting or for power, &c. The current in the mains thus consists of an accumulation or addition of an immense number of small currents, just as a river is the addition of an immense number of raindrops. As used for lighting, this river is again subdivided, just as an actual river would be if, near its mouth, the whole of its flowing water were taken away through endless channels for the purpose of irrigating land.

Mr Preece's illustration was this:—The earth is a huge,

* I hope I may be pardoned for ignoring, for an hour, the more modern view of the matter.

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although feeble, magnet. Suppose a man stands anywhere between the north and south magnetic poles of the earth,—facing one of them,—takes in each hand one end of a piece of flexible copper wire, and proceeds to use the wire as a skipping-rope. As he skips, a current will be generated in the wire, and will pass through it and round through his body from hand to hand. The current will be excessively feeble, but could be measured by sufficiently delicate apparatus. The man in this illustration takes the place of a steam-engine,—he simply employs mechanical energy derived from the internal combustion of certain organic materials to swing his arms and drive the wire, which forms his armature. The magnet of this dynamo is, of course, the earth. The illustration is really both exact and striking. Substitute a powerful steam-engine for the skipping citizen, a strong electro-magnet for the earth, replace the single wire with a cylinder or a set of bobbins containing a very large number of wires, and increase the speed of skipping to 400, 600, or perhaps 1,000 revolutions a minute, and you have the ordinary dynamo of commerce, the sort of machine which is used—in endless modifications of course—in all central stations.

It is important that you should not think of the central stations *generating* electricity in the sense of *creating* it. The machinery only makes existing electricity available for doing work, it creates nothing. Into the most difficult question of the real nature of electricity, and its relation to the "ether" which fills space,—if, indeed, it itself be not this ether,—it is obviously undesirable that I should enter to-night, even if the subject were one which I was competent to discuss. Without any pretence, therefore, to its being more than an approximate analogy, it may help you in following my further remarks if you think of things something in this way:—

Imagine a great pumping station for the supply of water under pressure to houses, for any purposes. Let there be beside it a very large reservoir of water. Let there be a double set of mains laid along the street, one main carrying the water to the houses, the other being in fact a drain to

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receive all the waste water from the houses, but carrying it back to the reservoir, and not to waste, if one may be allowed to suggest such a thing. If we further suppose the reservoir to be at a somewhat lower level than the houses, it is obvious that it might be standing full of water, containing any number of million gallons stored up, and yet the householder would be unable by any possibility to get a drop through the pipes into his house. (This, by the way, represents the present condition of Edinburgh in respect to electricity,—except that the pipes are not yet laid!)

Now, in the station beside the reservoir let us suppose a pumping-engine to be placed, and connected with the mains. Let it be arranged so as to draw water from the reservoir and force it under pressure through the pipes. No water is created, nothing exists which did not exist before, but now each householder can get whatever water he wants, whether to fill a bath or to work a lift, by simply turning on a tap. The engine simply does the work of pumping into his house. The reservoir never gets empty,—indeed, the quantity of water in it never changes, for I have supposed that all the water used finds its way back through the return main.

In like manner the whole space around us is a vast inexhaustible reservoir of electricity. The dynamo is merely a pump which forces it under pressure through certain definite channels. These channels are made double ("go" and "return"), in order to ensure greater certainty of working, but theoretically we might run a single main only, and allow the current to return by earth, just as we might allow the waste water to soak into the earth and so find its way eventually back to its reservoir. There are practical drawbacks about an earth return in both cases!

Just as we measure the flow of water in pounds per hour and its pressure in feet of head, so we measure the current (or rate of flow) and its "pressure," in suitable units, which we call ampères and volts respectively, the former being analogous to the flow of water, the latter to its head or pressure.

It must be borne in mind that whatever electrical pressure it may be most convenient to use in the mains, the actual

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pressure at the customers' lamps must be constant, and nearly everywhere is fixed at about 100 volts. A variation of as much as 4 per cent. upwards from this will increase the brilliancy of the lamps very much, but decrease their life, while a variation of 4 per cent. downwards would very seriously indeed diminish the light. As a matter of fact, therefore, all the supply companies do their best to keep the pressure at their customers' lamps as nearly as possible constant at 100 volts.

The companies supplying electrical energy in London may be roughly classified in two different ways, namely, (1) as using high or low pressure in their mains, and (2) as using alternating or continuous currents. With one exception the two divisions are conterminous.

The three high tension companies at present working are the Metropolitan, the London, and the House-to-House. The first named covers most of the residential district north of Oxford Street, and includes also Lincoln's Inn Fields and other parts of the region between Oxford Street and Fleet Street, and round Charing Cross. It has stations at Sardinia Street, Rathbone Place, and near Manchester Square, besides a low tension station at Whitehall, and a new station in process of erection at Paddington. The London Electric Supply Corporation has one generating station only,—at Deptford, about 6 miles from Charing Cross, but has also several distributing stations over its district, which covers an irregular and very widely extended area, including some of the best parts of Central London. The House-to-House Company has a small residential district at West Brompton supplied from one station.

Among low tension companies the largest is the Westminster Electric Supply Corporation, with which I am myself connected, and which has, for its area of supply, Westminster, (including the Houses of Parliament), Pimlico, Belgravia, (with Buckingham Palace), and Mayfair, marching with the Metropolitan Company along Oxford Street. It has three central stations,—one in Westminster, one in Belgravia, and one in Mayfair. Its district fortunately includes offices, shops, hotels, clubs, and private residences as well. The Kensington and Knightsbridge Company have a district at South Ken-

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sington mainly residential, with two stations and a battery station. The St James' and Pall Mall Company have the cream of the lighting in London,—that region in St James' which is familiarly known as "Club Land,"—which they light from one station in the centre of it. They are about to build another station for the northern part of their district. The Electricity Supply Company (Strand District) has a station near Covent Garden. The Notting-Hill Company has a district mainly residential,—its station has been very recently opened. In St Pancras the matter has been taken up by the Vestry itself, and its first station will soon be ready.

All the high tension companies mentioned use alternating currents, and all the low tension companies use continuous or direct currents. The Chelsea Company, however, which has a station near Sloane Square, distributes continuous currents at high pressure on a system which I shall describe later on.

It is, of course, impossible here to make any exhaustive comparison of the merits of the different systems adopted in London. I will say at once, also, that I am not one of those who think that any one system has all the merits to itself. Indeed, I think it is quite open to doubt whether, for instance, the system which is best adapted for St James' is also best adapted for Brompton. It is certainly not necessarily so, and I know personally that the different systems employed have been adopted in each case after careful consideration of their special circumstances by those responsible for the scheme. Whether or not a particular system is best in a particular place is not a matter which can be decided off-hand by mere expression of opinion, and without regard to the special conditions involved. I shall endeavour to give you, as fairly as I can, a sketch of the *pros* and *cons* of the principal points of difference between the systems adopted.

First, as to the main division which I have mentioned between the systems, that, namely, between distribution at high and at low pressure, or tension, as it is more often called. The analogy of water may here again be made use of. If it be required to do a given amount of work by water power, it can be done either by the use of a large quantity of water at a small head, or of a small quantity with a very high head or pressure.

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As we may otherwise express it, a given amount of energy may be furnished by the aid of water, either by sending a large quantity of water through the mains at a low pressure, or a small quantity at a high pressure. The work done, or the effect in energy, depends on the *product* of quantity and pressure,—*e.g.*, 100 pounds of water per minute at a head of 10 feet is equivalent to one pound per minute under a head of 1000 feet,—although it is to be noted that a much smaller pipe would be necessary to convey the one pound than the 100. Exactly the same is true of electricity. One hundred ampères at a pressure of 100 volts is the exact equivalent of 10 ampères at a pressure of 1000 volts. The importance of this point is easily seen. When a current of electricity passes along the copper conductor or wire, which takes the place in this case of the hollow water-main, a certain resistance is experienced analogous to the frictional resistance which accompanies the motion of water through a pipe. With a copper main of a given cross-sectional area this resistance increases—within certain limits—in direct proportion to the magnitude of the current,—that is, double the current gives double the resistance, &c. Moreover, this resistance, like friction, is accompanied by the generation of heat; the copper conveying the current becomes hot, and a certain point is easily reached at which the heat so generated is sufficient to injure the insulating material round the metal. Whether or not, however, the heat should be unduly great, all the work done against the resistance is absolutely wasted, for useful purposes, exactly as is the similar work done in pumping water. Practically it is found by most low tension companies that it is on these grounds inadvisable to allow copper mains to carry a current of more than six or seven hundred ampères per square inch of cross-section. As the output of a large station at full load is measured in thousands of ampères, this means that the trunk mains must have in all an area of several square inches, which is, of course, a very expensive matter.

On the other hand, the amount of current which a copper rod will carry is *not* affected by the pressure at which the current is circulating. Hence there is an obvious *primâ facie*

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advantage in the use of a high pressure. It allows the quantity of current for any given amount of electrical energy to be reduced just in proportion as the pressure is increased, and as the former only affects the size of the mains, the use of high tension—other things being equal—allows the weight of copper in the mains to be reduced very materially. Moreover, by using a pressure so high that the loss of head in forcing the current through the mains is negligible, or at least is proportionately very small, the generating station can be placed at a considerable distance, several miles for example, from the district supplied. In itself this is, of course, not desirable—indeed, it is most undesirable,—but naturally there may be places where the erection of a lighting station in the centre of a district which it has to supply is for certain sufficient reasons impossible.

I have said that the pressure of electricity in the customers' houses is a low pressure, and must be everywhere the same, whatever may be the pressure in the mains. Practically it is always about 100 volts. Hence clearly a distribution at high pressure would be impossible if there did not exist some ready means of changing the pressure from high to low at the customers' house. This requirement is met by the *transformer* or converter, which is at once the blessing and the trouble of the high tension systems. To explain to you the nature of this apparatus, I am sorry to say that I have to leave my hydraulic analogy, which appears to furnish no parallel case, and must take the thing just as it stands.

It is necessary before doing this to look for a moment at the other division between the London companies, namely, the use of continuous and alternating currents, pointing out at the outset that so far as house-lighting goes, there is no difference between them, but that as yet motors have practically only been driven by continuous currents. If you recollect my description of the way in which current is produced by a dynamo, you will see that that current really cannot be completely continuous. It consists of a series of very rapidly occurring successive flows of current. For all practical purposes, however, this current may be treated as continuous, for by a piece of apparatus called a commutator, which

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forms part of the dynamo, all the currents are made to flow in the same direction. A really continuous current is only furnished by a battery, but so far as all its leading characteristics and its measurement go, the current from a continuous current dynamo is identical with that furnished by a battery.

Such a current, as we shall see directly, cannot be transformed in pressure in the way I have alluded to. It is quite possible, however, to arrange a dynamo—which then requires no commutator—so that it delivers its current, not continuously, but in what may be called wavelets, swinging first forward, then back. An electric current of this kind is called an alternating current, and is used by all the high tension companies which I have mentioned in London. Each wave of current is complete in itself, and occupies generally from one-eightieth to one-hundredth of a second, forming a complete cycle of what—in default of a better expression—we may call a go and return current, and between each pair of waves the current is zero, that is, the flow ceases absolutely, although for an infinitesimally short time.

The "transformer" used with alternating currents is based on the following phenomena:—If two conductors of a suitable kind, and forming part of closed circuits, are placed near together and parallel, but without any contact (that is completely insulated from each other), and a current be passed through the one, at the instant of starting it a current will be found to traverse the other. This latter current (which is called an *induced* current) does not continue, whether or not the originating current goes on steadily; it is instantaneous only, occurring just at the instant of starting. But at the instant when the first or primary current ceases, another induced current appears in the second wire, this time in the opposite direction to that in which it formerly appeared. If, therefore, the primary current starts and stops eighty times per second, the induced or secondary current will be a similar discontinuous current having the same frequency and therefore available for the same purposes. If the primary and secondary wires be alike, the tension of the two currents as well as their quantity will be the same. By using, instead of a straight wire, a helix of a certain number of turns to form the primary, and

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for the secondary another helix containing a different number of turns, the induced current may be made either higher or lower in pressure than the primary. The quantity of current, of course, varies inversely as the pressure, so that the amount of energy transmitted is not altered, except so far as internal losses affect the efficiency of the apparatus. In principle the transformer is simply a pair of coils such as I have mentioned. Remember that there is no electrical contact whatever between the coils, although they may be in very close proximity. The high tension main goes from the station to the primary coil of the transformer and back again to the station without actually entering the house. The low tension main goes from the secondary coil of the transformer round the house circuits. Apart from accidents, therefore, the high tension current can never actually get into the house mains. Figure 1* shows the general arrangement of the circuit and transformers used by the Metropolitan Electric Supply Corporation. A is the central station from which a series of circuits are led through the district. D represents a dynamo, with its two poles connected to one of these circuits. It will be seen that soon after leaving the station both positive and negative wires are looped into rings; the ring may, of course, embrace many streets. B, B, are houses in the district to be supplied with current. There is a transformer, T, and a meter, M, in every house. Wires from the mains enter the transformer, pass through the primary coil, and come out again. The secondary coil is shown separately connected with the lamp circuits of the house. The meter by which the electric energy is measured is on the house circuit. The pressure in the mains is 1000 volts, the pressure in the house circuits may be either 100 volts or 50 volts according to the wish of the consumer. Mr Frank Bailey, the engineer to the company, is of opinion that a 50-volt house circuit is better than a 100-volt house circuit, from the view at any rate of the life of the lamps. The system of looped mains shown in the sketch is due to Mr Bailey, and has been adopted so that every house on a circuit can be reached round the loop in two ways, thus

* The same lettering is used in all the figures.

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greatly reducing the risk of breakdown through an accident on the mains. One or more circuits may be connected to and worked from the same dynamo at the station, but at present it has not been found possible here to put more than one dynamo on to the same circuit, or, in technical language, to run the dynamos in parallel.

The system adopted by the London Electric Supply Corporation, which has been from the commencement designed and worked out by Mr Ferranti, differs from that just described in very many respects. Its general scheme is sketched in figure 2. This company has, rightly or wrongly, assumed that it was advisable to make its station away from London. Its generating station is on the Thames at Deptford, about six miles from Charing Cross. Current is there generated by large dynamos at a pressure of 2500 volts. It is transformed at once up to 10,000 volts, and transmitted to London at that pressure by specially insulated mains of most ingenious construction. These mains lead to two or three sub-stations in London itself, one in Bond Street, one near Charing Cross, &c., which contain transformers only, and where the current is transformed down to 2500 volts again, and distributed at this pressure through the streets. In the customers' houses it is transformed down to 100 volts, just as in the last case. It is intended ultimately to generate current at the full pressure of 10,000 volts so as to save the first transformation. There can be no doubt that with such appliances and knowledge as we possess at present the drawbacks of having three transformers are very great indeed. Whether or not they are more than counterbalanced by the advantage of having a station down the river is a matter which must finally be decided by the result of practical working.

The system used by the House-to-House Company does not differ in essentials from that of the Metropolitan Electric Corporation, except that the pressure in the mains is 2500 volts instead of 1000.

I have said above that the transformer was the trouble as well as the blessing of the alternating current system. Whilst it enables a saving to be made apparently throughout the

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whole of the mains, this saving is accompanied not only by the very notable cost of the transformers, but also by such a very great loss in efficiency that it is now most improbable that any new high tension company will be started *in an urban district* on any of the plans I have described; that is to say, with a transformer in the house of each customer. A perfect transformer ought always to give in its secondary circuit exactly the same amount of energy as that which has passed through its primary circuit. No actual transformer does this, but the efficiency of good transformers at their full load is very high—often over 90 per cent. But the full load of a house transformer corresponds to the current necessary for all the lights in the house—the transformer must of necessity be large enough to allow for this. All the lights in a house, however, are not on at once half-a-dozen times in the year, in general the *maximum* load in a house is less than half its full number of lamps, its average load not more than a quarter, and, of course, for many hours out of every twenty-four no lamps are burning at all, so that the load is zero. Unfortunately, the losses in the transformer continue all the twenty-four hours, whether or not there is any current passing through the secondary coil. These losses are more or less proportional to the full load for which the transformer is designed, and, taking all together, they are most serious. Such authentic statistics as I have been able to obtain show that the consumption of coal in a central station per unit passed through customers' meters is, at least, twice as great with the high tension companies as with the low tension, the figures being 17 to 20 pounds with the one, 8 to 10 pounds with the other. The greater part of this difference is probably due to the transformer losses. In fact, a company which has 500 transformers in its customers' houses is practically keeping as many small fires burning day and night in as many cellars at its own expense. Of course, whatever these losses may be, they do not affect the meter readings, and the customer has not got to pay for them. To remove these losses a change in method is now proposed, and I believe the London Company, at least, are taking active steps in this direction. The proposal is to remove the transformers from the customers'

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houses altogether, and to concentrate the transforming plant at certain sub-stations, where the load will never be zero, and where the number of transformers in use can be altered from hour to hour as the load varies, so that the instruments actually in use can always be worked with fair economy. This change, the wisdom of which I do not doubt, and which is being advocated most strongly by some of our best engineers, is a very far reaching one indeed, although it seems at first to affect only a matter of detail. For, in reality, it necessitates giving up at once three-quarters of the high tension mains, and laying new low tension mains suitable for 100 volts pressure, from each sub-station over the whole district, exactly as in a low tension system. If this has to be done, it is obvious that the greater part of the saving in first cost due to the use of high tension mains, disappears at once, and as the system of "banking" transformers is as yet very little practically known, it remains to be seen to what extent it attains in practice the results expected of it. I understand that this is the system which it is proposed to use in the City of London itself, by the new company which has just been started for the purpose of lighting that district.

The mains used by low tension companies generally divide themselves into two parts, which are called feeding and distributing mains respectively. The latter are the mains to which the house services are directly attached, and which cover the whole of the streets in the district. They are common to all systems of low tension distribution, and will have to be used equally by alternating current systems, if these adopt transformer sub-stations in the way just alluded to. The cost of the distributing mains is considerably very much more than half the total cost of the mains, a point to be kept in view. Feeders or feeding mains are lines radiating directly from the central station, and carrying current from it to certain fixed points, called feeding points, where they join the distributing mains. These feeders are the mains which have the largest section of copper, but they are few in number, and their total length is not nearly so great as that of the distributing mains. In a modified high tension system, such as mentioned above, each feeder would be replaced by a

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line of very much smaller sectional area of copper, having a sub-station with transformers at the point where it joins the distributing mains.

The low tension companies try, as far as possible, to use bare copper strip carried on porcelain or glass insulators. This strip is enclosed in concrete culverts or iron conduits. The advantage of its use is clear, when it is remembered that the cost of the ordinary india-rubber insulation of any cable is considerably greater than the actual cost of the copper insulated. The use of bare copper, properly insulated, is quite safe up to a pressure of about 200 volts, but, of course, is impracticable with high pressures.

The systems adopted by the low tension companies in London vary somewhat among themselves, but have certain points in common. All of them use continuous currents, and all of them but one are schemed to generate electric energy at a pressure of about 200 volts (not 100), so as to save to this extent in their mains. The distribution to houses at 100 volts, without the use of transformers or any other apparatus, is effected by a sub-division of the 200 volts into two sections or parallels of 100 volts each (by the use of what is called a third wire), and dividing the consumers, as evenly as may be, between the two sections.

Figure 3 shows the way in which lights can be put on a three-wire system in this fashion. As compared with direct distribution at 100 volts, there is in this arrangement the very great economy that the amount of energy carried by means of a given section of copper is doubled, while the difficulties of insulation are not considerably increased. The three-wire system is shown in fig. 3 as it is carried out by the St James' Company. Two dynamos, D and D_2, are connected "in series,"—that is to say, the positive pole of one to the negative pole of the next. Each dynamo generates current at 100 volts pressure. The difference in pressure, therefore, between the positive and negative mains is 200 volts. A middle, or third wire (shown by a dotted line in all the figures), is connected between the dynamos, and is carried round the circuit, the houses, B, B, &c., being placed alternately on the one and the other parallel, as sketched, so

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that the pressure in the house is never more than 100 volts. If an exactly equal number of lamps was alight at any time on each of the two parallels, no current would pass through the third wire. But, under ordinary circumstances, the number of lamps on the two parallels is not exactly equal, and one of the dynamos will have to work a little harder than the other to make up the difference.

The use of storage batteries or accumulators is possible only upon a continuous current system. As to the use and economy, or otherwise, of batteries, there has been very warm controversy. In London, Mr R. E. Crompton, the engineer of the Kensington and Knightsbridge Company, has always been the leading advocate for their use, and has succeeded in very greatly improving their design. I am using them in my own district, and, while admitting that it is possible to exaggerate their advantages, I find them so useful that I could on no account be without them. The St James' Company, on the other hand, whose conditions of working are no doubt somewhat special, scarcely use them at all, and have been very successful without them. My plan in the work of the Westminster Company has been to use them as a stand-by and regulator during work, and for taking up the whole load during the small hours of the morning, or at other times of minimum demand, thus allowing the station to be entirely "shut down." This is a matter of which the immense advantage and convenience probably appeals more to the engineer than to the consumer. I pass from five to six per cent. of the whole of the current generated through the batteries, and on that fraction I lose, on account of the imperfect action of the batteries, fifteen or sixteen per cent. measured in energy. I therefore pay something under one per cent. in total efficiency as the price for the convenience of using batteries, even supposing that they do not (as I believe they do) very much more than make up for this, by obviating the necessity for working boilers and engines at all during hours of minimum demand. The system used, and I believe originated, by Mr Crompton is sketched in fig. 4. It will be seen that the batteries are placed in parallel with the dynamos, and the third

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wire connected to the middle of the battery only, and not to the dynamos. Instead of two dynamos in series, one dynamo only is used, and it generates current at 200 instead of at 100 volts. Fig. 5 shows the arrangement of mains which I have adopted in my own district. It may be rather called a double two-wire than a three-wire system, and has enabled me to make a very great saving in copper, as compared with the ordinary three-wire distribution.

The Chelsea system, to which I have alluded, is one which General Webber has again lately described in detail before the Institution of Electrical Engineers, and which possesses much special interest. A single central station distributes continuous currents, at a pressure of from 500 to 1500 volts, to a number of battery stations scattered through the district. The current does not go direct to the consumers at all, but goes entirely to charge accumulators. The pressure is maintained by charging the cells in series, either in one station or in several simultaneously. After being thus charged, the cells are discharged in parallel, so that each set gives a discharging current of about 100 volts pressure. The batteries are so arranged that one part is always delivering the current to the circuit, while the other is being charged, until the charge is complete. The leading advantage of this system, a very great one, is that the load on the engines is more or less independent of the fluctuation of customers' demands, and is therefore steady and fairly heavy while it lasts, so that the engines can work with considerable economy. The drawback is, that the whole of the current has to pass through batteries, which means, at the very least, a loss of 15 per cent., and probably more nearly 25 per cent. in energy, besides all the other losses in the mains, &c. Time only can show on what side the balance of advantages lies.

In order to supplement the batteries at times of the heaviest loads in winter, when in London day is turned into continuous night, and when therefore the charging can hardly overtake the discharging of the cells, the use of what are called continuous current transformers has been commenced. A continuous current transformer is simply a combination of a motor and a dynamo, so arranged that the motor part can

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be driven by a current of 500 volts pressure while the dynamo part gives out, like the batteries, a current of 100 volts pressure. This apparatus is an exceedingly interesting development in electrical engineering of which we are certain to hear more.

In conclusion, you will perhaps like me to say a few words about the cost of electric lighting in houses and streets, as this is a matter which may very soon affect you closely in Edinburgh. Street lighting is a matter I have not mentioned yet, because there is as yet none in London, although the City itself is shortly to be lighted by a recently formed company. About public lighting the point to be remembered is, that in the streets people are not content with electricity unless it gives them 20 to 25 times as much light as they are getting from gas. Under these conditions it will cost at least four or five times as much as gas, and quite probably more. Light for light it will not cost more than about a quarter the cost of gas, and in any given case a community has simply to make up its mind whether it is worth its while to pay extra, although at a cheaper rate, for a very much better commodity.

As to private lighting, however, the figures are very different. Here the cost depends to a very great extent upon the amount of common sense which has been used in the wiring and lighting of the rooms and the amount of care which the householder is willing to exercise. If each light in a room has a separate switch, so that lights can be added as required, one at a time,—if the lights are not covered up and darkened with frosted or iced or opal shades or glasses, which may be pretty, but which certainly absorb from 40 to 70 per cent. of the light, —if people are content to replace five candle-power gas-burners with 8 candle-power lamps and do not insist on 16 's,—if every room has one switch placed just inside its door so that it can be turned directly the door is opened,—then the cost of lighting a private house with electricity will probably be about 25 per cent. in excess of gas, if gas is 3s. per 1000 cubic feet, and electricity 8d. per unit. Here, where I am told that gas costs 4s. 6d. per 1000 cubic feet, there is no doubt that a private house can easily be lighted well with electricity at a less cost than with gas.

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But it must be clearly understood that this estimate of cost does not apply if the house is so wired that two or three lights have often to be turned on when only one is required,—or if the switches are so placed that it is inconvenient to get at them in the dark, so that the light is left on when the room is empty instead of being always turned out,—or, worst of all, if the house-mistress thinks "the little wire in the lamp," as she calls it, a detestable object, and insists on disguising it by ornaments which absorb the greater part of the light generated, and therefore necessitate an expenditure of double or treble the current at an exactly corresponding increase of cost.

I try to put this very clearly in order that there may be no disappointment later on—at least, so far as I can obviate it—with the bills which will come in from your electric lighting company. Let me emphasise one point still more. If the electric light had to be left on in unused rooms as gas is left on, its cost would be twice as much as that of gas. It can only be brought down to the figure I have named by adopting rigidly the plan of turning it out always on leaving the room. With electricity this is so small a matter that practically it is no trouble whatever.

As to hotel and club lighting, where the same economy cannot be practised, and where, above all, the proportionate number of lights on at one time is always much greater than in a private house, the cost of electric light, even with all the economy possible, will hardly be less than double that of gas at 3s., supposing the electric light to be charged at the rate of 8d. per unit.

For shop lighting no figure can well be given, for the simple reason that the owners of shops generally use the light partly as an advertisement or attraction, and therefore use very much more than there is the least occasion to use,—finding no doubt—as they are the sole judges of what is good for their business—that it pays them to do so.

Actually the cost of electric lighting is known with great exactness to be a farthing per hour for an eight candle lamp, and a halfpenny per hour for a 16 candle lamp, when the charge for current is 8d. per unit. On this basis any one

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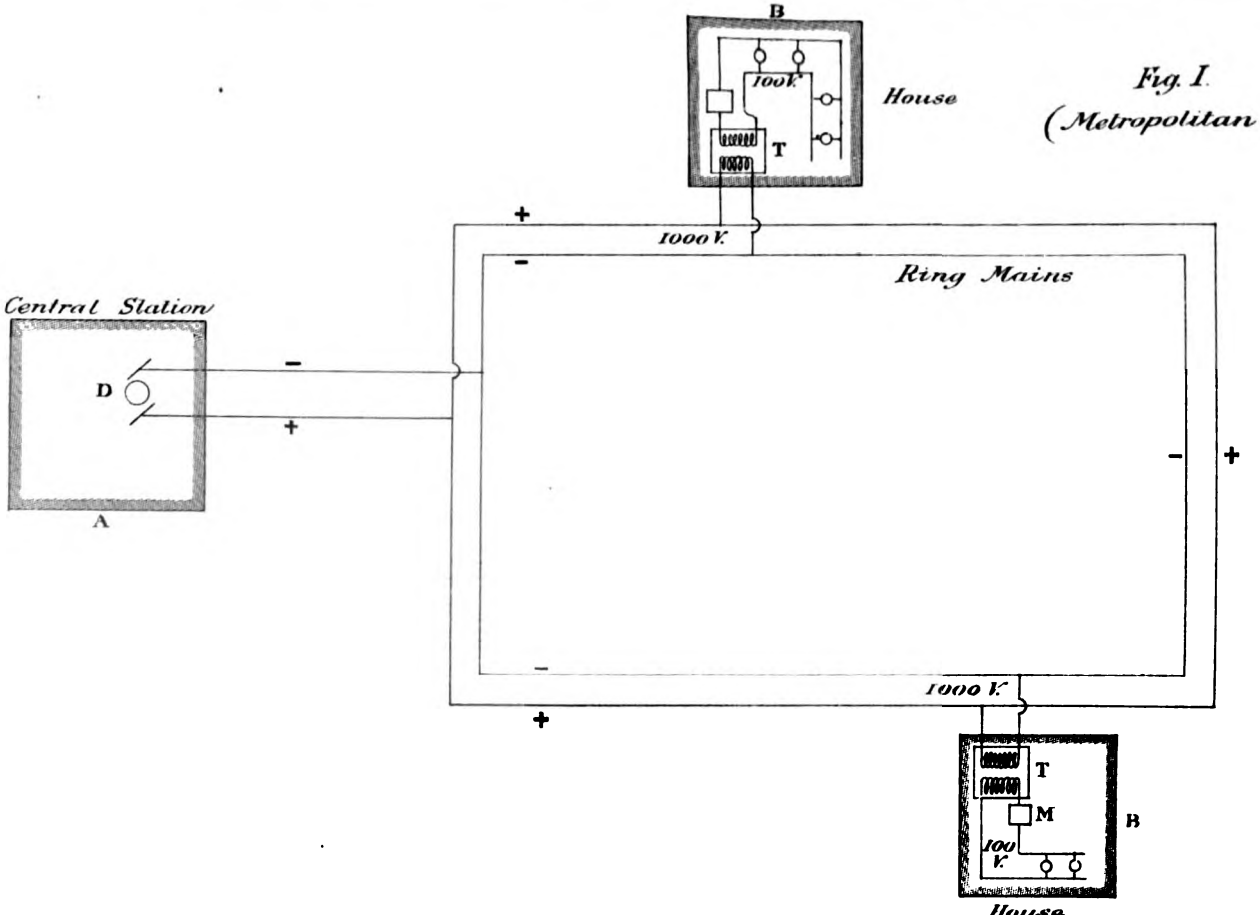

Fig. I.
(Metropolitan Co.)

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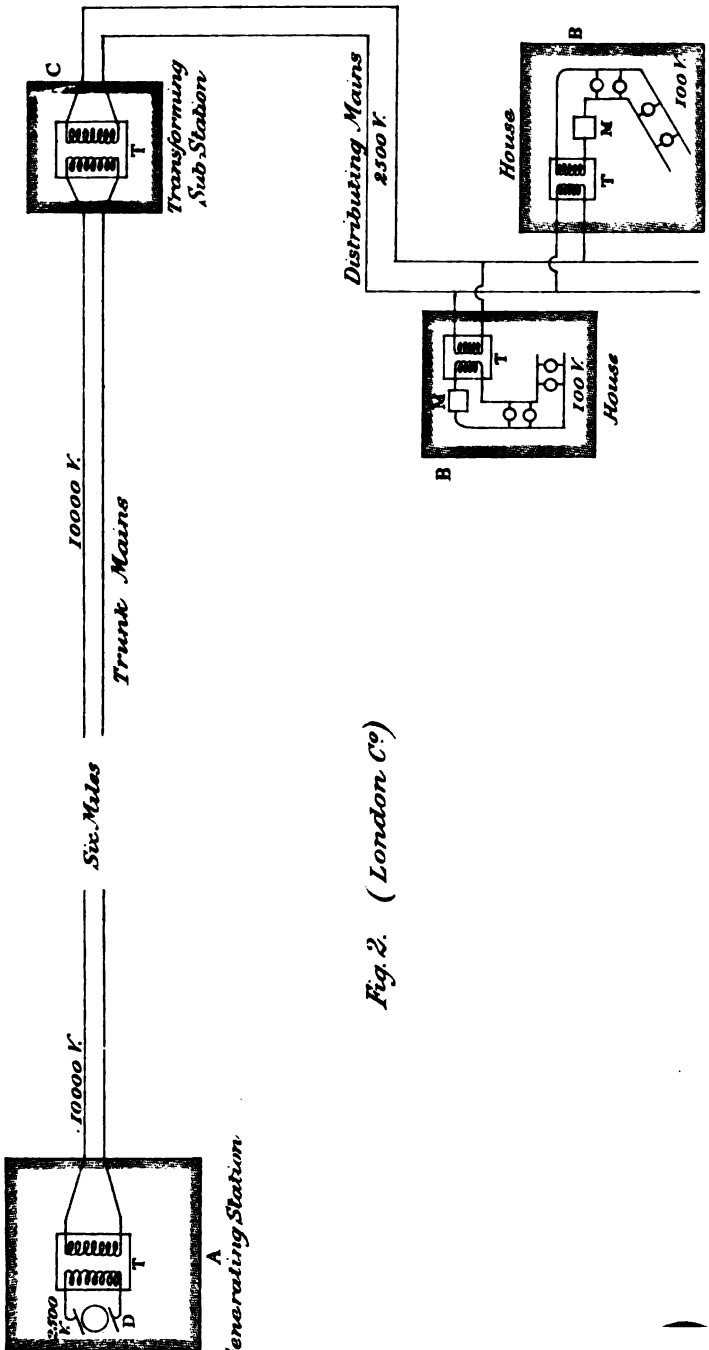

Fig. 2. (London Co.)

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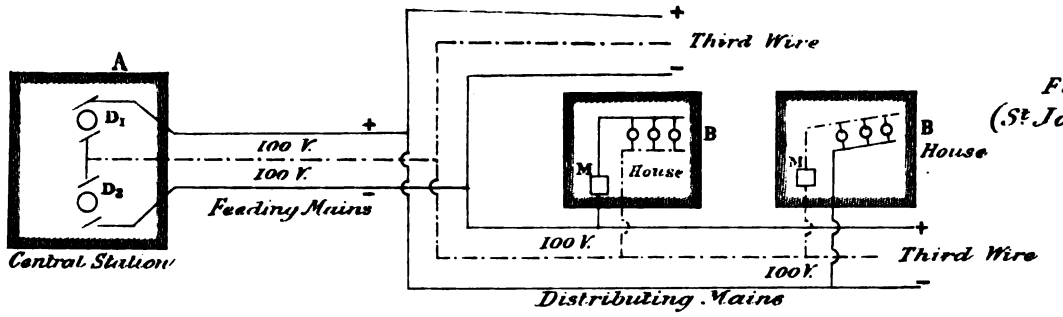

Fig 3.
(St James Co)

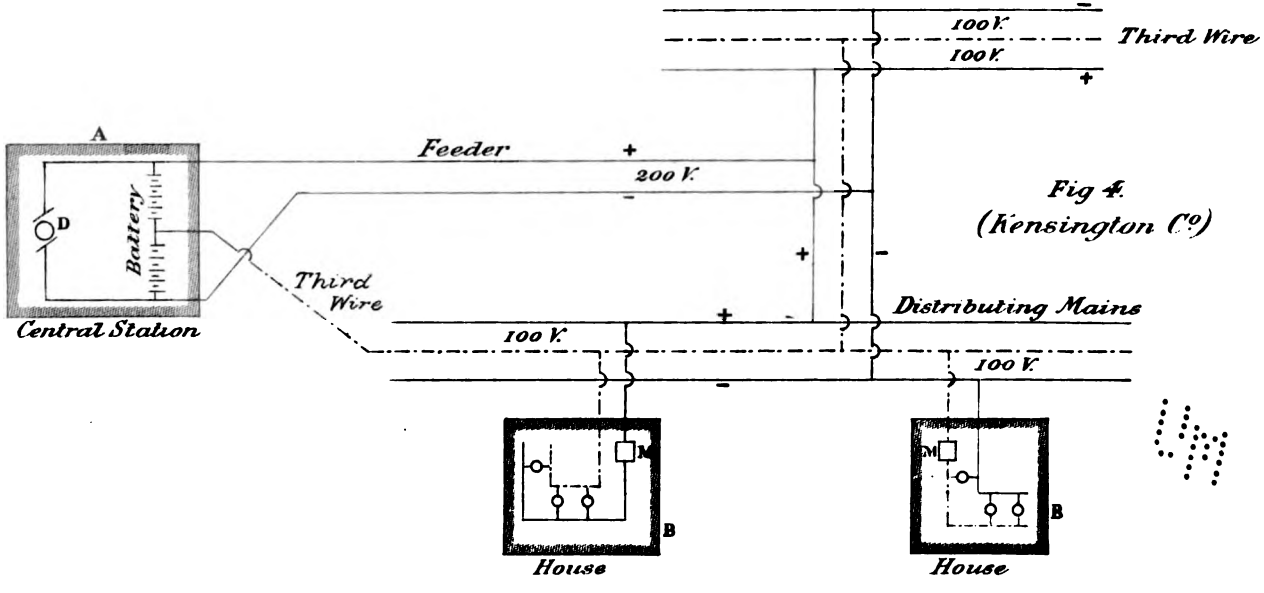

Fig 4.
(Kensington Co)

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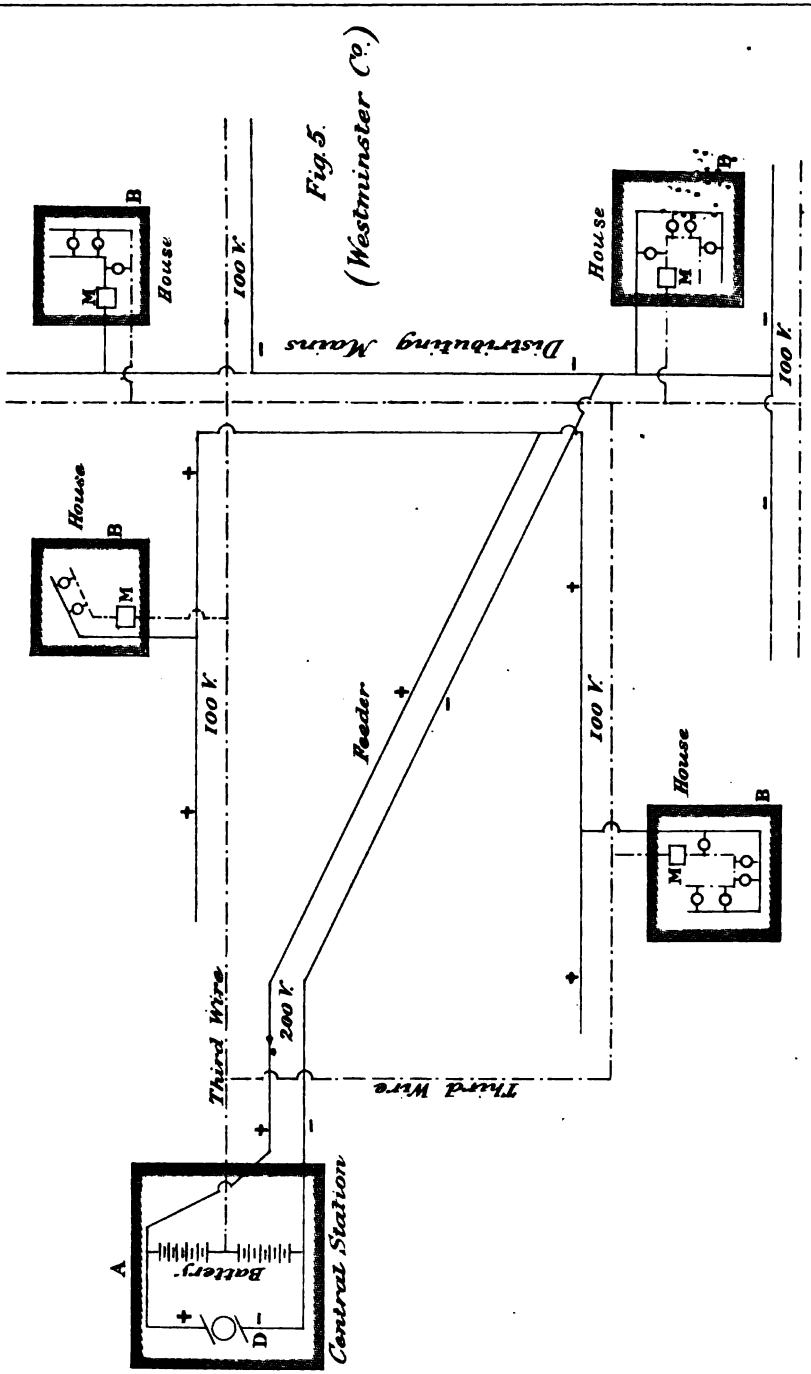

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can make out beforehand the exact cost of burning any number of lamps for any known number of hours.

My remarks have already extended to such a great length that I will not say anything about the light from the points of view of health, comfort, cleanness, coolness, and general convenience. No one who has ever tried it has ever expressed the least doubt on these matters, and they have for long been practically beyond question.

I can only conclude by expressing the hope that here in Edinburgh you may soon be able to verify for yourselves the universal opinion of those who use the light, and I shall be exceedingly glad if my remarks this evening have any influence whatever in helping forward the movement in which I understand your Town Council is already taking the first steps for supplying the city of Edinburgh with the electric light.

A Reflecting Galvanometer with Adjustable Periodicity for Physiological Research. By R. MILNE MURRAY, M.A., M.B., F.R.C.P.E.* (With Plate.)

The study of the electrical phenomena of muscle and nerve has absorbed the attention of a large number of physiologists during the last thirty years. These phenomena are of a highly complex character, being greatly modified by a variety of conditions. These variations represent in many cases very vital changes in the condition of the tissues under observation, and their recognition becomes matter of great importance in the study of the subject. In order to permit of and facilitate their observation, a highly elaborate and very delicate set of apparatus is necessary, and much ingenuity and skill have been expended in devising suitable instruments for the purpose. But, though numerous instruments of many sorts are in constant use, it happens every now and then in the course of a research that some modification of a recognised instrument, or the devising of an entirely new

* Read before the Society, on 9th March, 1891.

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one, becomes necessary for the purpose in view. I have been studying for some time the changes connected with the electrical polarization of tissues under excitement, &c., and have had to turn my attention especially to the subject of galvanometers for the purpose of recognising and measuring the changes in direction and amount of current developed under such conditions. Accordingly, I have found that while the instruments in ordinary use have in a high degree some of the qualities necessary, they are all of them deficient in others which are of importance, and sometimes even essential.

For the particular kind of work to which I refer, there are three special qualities demanded in a high degree.

1. Great sensitivity.
2. A high figure of merit.
3. Aperiodicity.

(1) By the first we mean that an instrument whose needle is deflected under the influence of a current will change its deflection perceptibly with a very slight change in current strength. We are, with such an instrument, able to recognise any slight changes in the current strength under observation. This, to the physiologists, is of the utmost consequence, since the currents he deals with are, as a rule, undergoing frequent, almost constant, changes, indicating the nature and occurrence of phenomena under investigation.

(2) A high figure of merit is also required. By this we mean the *reciprocal of the strength of the current which will move the needle from zero to one degree on either side.* A high figure of merit enables us to recognise and measure exceedingly minute currents, a point also of great moment to the physiologist whose current strengths are usually measured by minute fractions of an ampère.

(3) By the quality of *aperiodicity* we mean that when the needle is deflected it comes to rest quickly, and enables the current to be measured from the moment it begins to flow. It is obviously impossible to measure a varying current with a galvanometer whose needle tends to oscillate, because the very variation in the current keeps up the oscillations, and prevents the needle ever coming to rest.

These, then, are the special requirements in a galvanometer

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for physiological research, and I propose to show you in what way I have endeavoured to combine them in the instrument I have here to-night.

The only type of instrument which at all enables us to obtain these qualities is the Thomson Reflecting Galvanometer. No other form can approach this in sensitivity, and this, after all, is the primary desideratum.

Thomson's instrument (as is well known) consists of a short light needle suspended in the core of a vertical coil of wire by a cocoon fibre. To the needle is attached a mirror on which a beam of light is thrown and reflected, and the movements of the needle are read by the movements of the reflected beam over a graduated scale.

The sensitivity varies as the number of turns of the coil and their nearness to the needle, and also depends on the strength of the magnetic field of the needle. This last can be increased by using several instead of one short needle.

When greater sensitivity is required, this can be further obtained by making the instrument astatic. This is done by fixing the needle to the upper end of a light staff of aluminium wire, while another set, with their poles in the opposite direction, are attached to the lower end. The staff is suspended in such a way that the upper set of needles lies in the centre of one coil of wire, while the lower lie in the centre of another. The connection between these two coils is so made that the current passes in opposite directions through each, and thus, by Ampère's laws, the effect of a current travelling through the whole system is that the current in the upper coil tends to deflect the needle in a certain direction, while the current in the lower has a similar effect.

Further, the system is free from the controlling influence of the earth's magnetism, because the pull of the earth on one set is neutralised by the pull in the opposite direction upon the other.

Such an instrument as this, then, gives us the first two qualities of a galvanometer in a high degree, sensitivity and high figure of merit. These are secured by (1) a fine suspension in which resistance to twisting is a minimum, (2) a

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strong magnetic field, and (3) a long coil of very thin wire.

For the purpose of adding the quality of aperiodicity to these galvanometers, three principal methods are in use.

(1) That due to Sir William Thomson himself, known as air damping. In this the needle, mirror, and suspension are enclosed in a little air-tight box, with glass ends placed in the centre of the coil. The ends can be pushed in or drawn from the mirror whose movements are checked by the sort of air cushion or buffer against which it beats.

This method has the great objection:—

1. It cannot be applied to the astatic form.
2. It involves a very short suspension, or the tube becomes so large that the needles are removed from the coils, and sensitivity is lost. Thus it sacrifices figure of merit by shortening the suspension or sensitivity by removing the coils from the needle.

(2) The second method is due, I believe, to Edelmann of Munich, whose galvanometers are all provided with it. In this, which is termed magnetic-damping, the needle is made to swing in the centre of a mass of copper in which each swing of the magnetic system induces a current in the opposite direction which produces a magnetic lag or pull tending to stop the needle. This is specially applicable to horizontal instruments. It has been adapted by Elliott Brothers to a vertical instrument made by them for Professor Burdon Sanderson of Oxford. They have placed two curved masses of copper in the upper coil of the Thomson instrument, so as to act on the upper needles. This acts very nicely so far as the damping is concerned, but sensitivity again suffers on account of the space occupied by the copper and the distance of the coils from the needle in consequence.

(3) The third method consists in making the whole suspended system so light that its inertia being reduced to a minimum it starts and stops with the current and follows its variations in the same way. This is a very effective method within certain limits, and has been recently carried to great refinement by the Cambridge Scientific Instrument Co. in a beautiful set of galvanometers they have lately issued.

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But it has this disadvantage that the needles are so thin that they can hold but little magnetism and rapidly lose their charge, which of course results in corresponding diminution of sensitivity after a time.

Such, then, being a summary of the methods in use, and an indication of their defects, I proceed to describe the special features of the instrument I have constructed, to meet, as far as possible, the special requirements of the physiologist.

1. *Frame Work and Stand.*—The instrument is built on a thick block of polished vulcanite, which is supported on three legs with levelling screws, raising the base 3½″ from the table. From the base rise two strong gun-metal pillars, *a*, *a* (fig. 2), which are joined above by a bridge-piece, *b*, from which the magnetic system is suspended. The coils are placed in metal boxes fixed to vulcanite plates which are clamped to the gun-metal pillars by the clamps at *c*,*c*,*c*,*c*.

There is an arrangement on the bridge-piece, *b*, by which the pin carrying the suspension can be centrally adjusted.

2. *The Magnetic System.*—The method of arrangement adopted is on the principle due to Mudford.

The needles are arranged in two groups, an upper with all the "Norths" one way, and a lower with all the "Norths" in the opposite way. The magnets are 10 in number (5 in each group), and are of greater mass than usual, and are thoroughly saturated. They are fixed to the staff by an aluminium plate, and they and the mirror can be rotated round the staff in order to enable them to be brought absolutely to the same plane. This is an advantage, as compared with the ordinary arrangement in which the needle and mirror are *cemented* to the staff, and it is often exceedingly difficult to secure their lying in the same vertical plane—a matter obviously of considerable moment.

The mirror, *m*, is not attached to the upper set of needles, as is usual, but is fixed to the staff half way between the two. This enables us to avoid coring out the upper coil in order to allow the beam of light to reach the limits of the scale. By this means a much larger number of wire turns can be applied to the upper front coil; with obvious advantage to the sensitivity.

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3. *The Damping Arrangement.*—The arrangement for securing aperiodicity is a form of liquid damping, with a fine adjustment for regulating the amount. The staff carrying the magnets is prolonged downwards past the lower coil, and ends in a vane of aluminium. This vane may be spear-shaped or "paraboloid" in section. This vane hangs on a cup of oil or other fluid, *d*, which cup can be raised or lowered by means of a fine micrometer screw (50 turns to the inch), moved by a large milled-head, *e*. By this means the vane can be made just to touch the "skin" of the liquid, or can be partly or wholly submerged, and in this way any degree of aperiodicity can be secured.

This arrangement has a special value in obviating a difficulty in many laboratories where the support for the galvanometer is attached to the wall of the building, and where the instrument is accordingly affected by movements in the same or other rooms. These tremulous oscillations are very troublesome, but they can be obviated by having the vane sharply pointed and the cup so adjusted that the tip *just touches* the "skin" of the oil. The magnetic system thus works as it were between two frictionless (or almost frictionless) pivots—the fibre above and the point of the vane on the liquid below; and, unless the vibration in the instrument is very great indeed, it does not appear in the index.

For perfect aperiodicity, without loss of sensitivity, I find the blunt vane preferable.

The framing and case of the instrument were made by Mr William Hume, Edinburgh. The magnetic system was made by Messrs Elliott Brothers, London, and the coils were wound by Messrs Nalder Brothers, London.

The total resistance of the four coils in series is 12,650 ohms.

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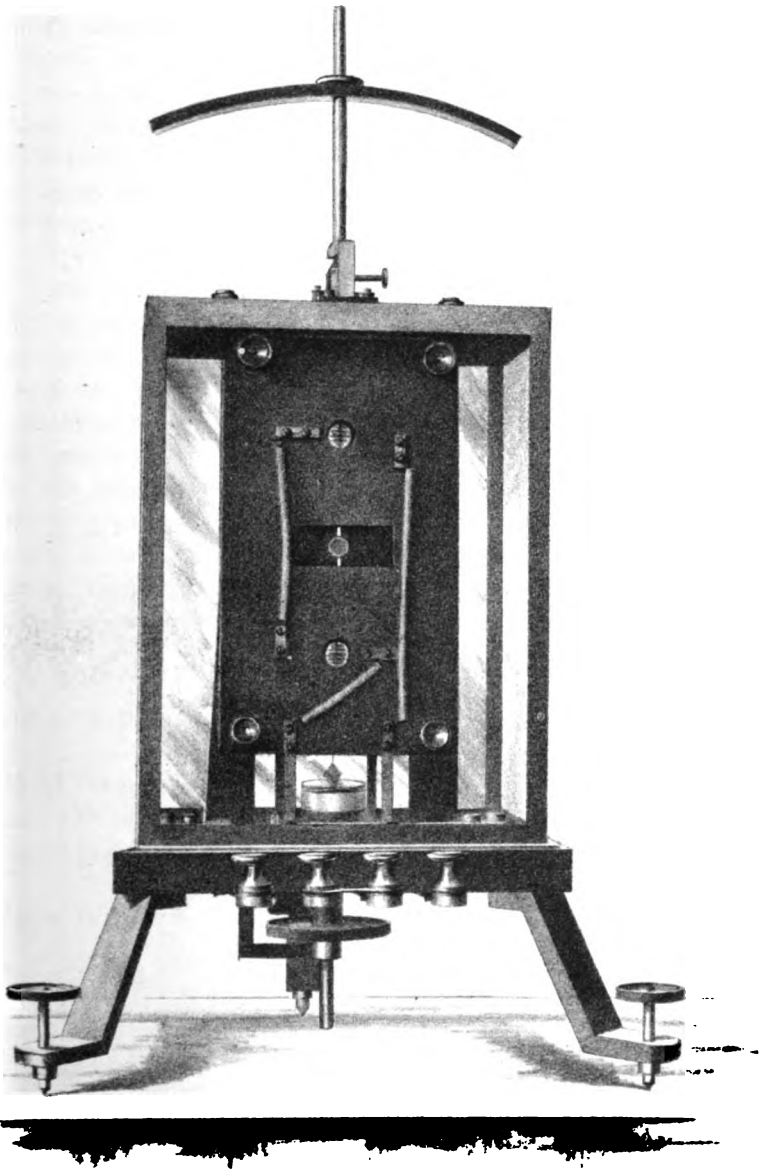
PLATE I.

Dr. Milne Murray
on a
GALVANOMETER
WITH ADJUSTABLE DAMPING.



J.T. MURRAY

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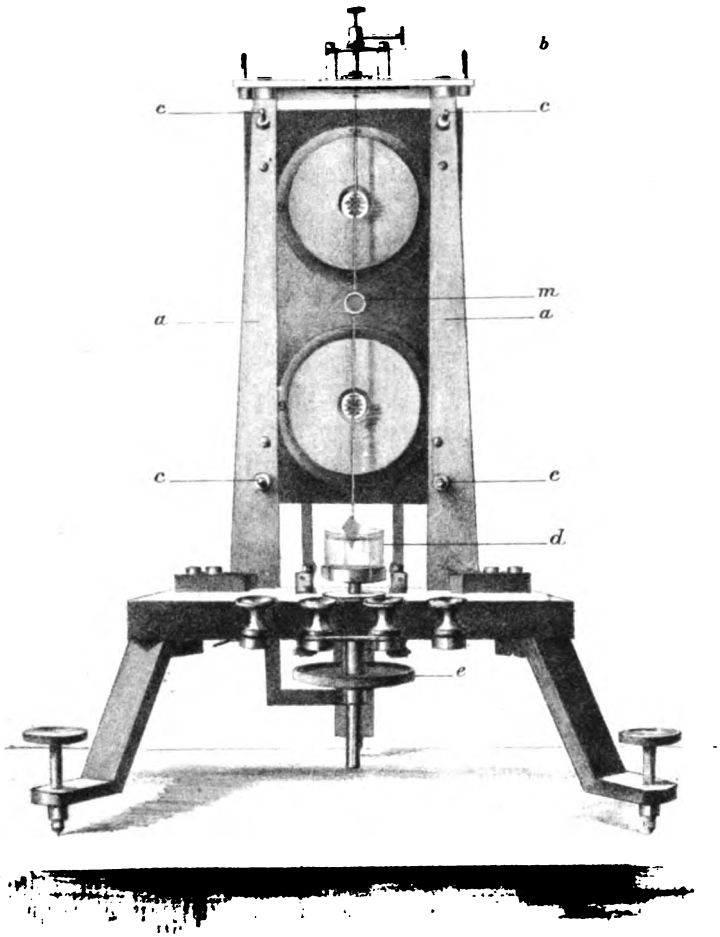

VIEW OF INSTRUMENT WITH FRONT COILS REMOVED.

J.T.MURRAY

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On an Electrical Bench for Physiological Research. By R. MILNE MURRAY, M.A., M.B., F.R.C.P.E.* (With Three Plates.)

This bench is intended to provide an arrangement by which any variety of electrical current may be obtained with the least possible trouble for the purposes of physiological investigation. In the investigation of the physiology of muscle and nerve, for example, it is often necessary to employ measured strengths of galvanic and faradic currents of definite periods. This requirement is met in different ways by different experimenters, and most properly equipped laboratories possess apparatus which, by a little trouble, can be adapted to meet the necessities of each special investigation. When an investigator is working in such a place and has the advantage of skilled assistance, a little thought and ingenuity will usually enable him to arrange the apparatus to suit his purpose. But when one is working alone, or with small resource in the way of skilled help, it is often a matter of some trouble and inconvenience to arrange the appliances for any given experiment, and much time is lost in re-adjusting the instruments to obtain some slight variation of electrical current for stimulation or other purposes. This bench is accordingly arranged in such a way that a current of any required sort, in any direction, of any required strength and rate, may be obtained by adjustment of keys, clamps, &c., which involves a minimum of time and trouble. All these adjustments can be made without leaving the seat at the experimental table, so that mechanical or skilled assistance is quite unnecessary in many researches where they are otherwise indispensable. This is, of course, a matter of considerable moment to one working in a private laboratory, and it is probably chiefly by such that its advantages in time and trouble saving will be specially appreciated.

The various parts of the apparatus are fixed to a table made of well polished butternut; the connections between the various keys relays and terminals being made by properly

* Read before the Society, on 12th January, 1891.

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insulated tinned copper wires which pass through and run from point to point under the table.

The rate of interruption of the current (and of consequent stimulation) is determined by the vibrations of a reed A (Plate II.), whose length and period can be altered by means of an adjustable clamp B in which it is held.

A platinum point attached to A dips into the mercury cup C, and closes the circuit of the battery E through the magnet D. This pulls the spring out of the mercury, breaks the circuit, and the spring falls again into the mercury. In this way the reed is kept vibrating at a rate determined by its length between the clamp B and its free end. The details of this part of the instrument are shown in Plate III., fig. 1.

If the block F be plugged, the circuit is confined to the spring and the magnet. But if F is unplugged, then the current will pass round GGG. If, now, any of the blocks $H_1H_2H_3H_4$ be unplugged, the circuit will include the magnet of the relays S,I,K or L respectively.

Let H_1 be unplugged, then the relay S will repeat the vibrations of the spring, and, closing the circuit of the battery N, will actuate the time-marker T, which will record the number and rate of the vibrations of the spring on the drum V.

Now, let the block H_3 be unplugged, the relay K will then act and make the circuit of the battery N_3, which includes the primary coil P of a Du Bois Reymond induction coil. This will induce currents in the secondary coil R, and so excite the nerve-muscle preparation W, whose contractions will be recorded by the lever U, immediately under the markings of the signal T. Thus the rate and moment of stimulation will be recorded by T, while the result of that stimulation will be recorded by U.

Similarly, if H_2 be unplugged, the relay I will close the circuit of N_2, and galvanic stimuli will be transmitted to the nerve by the electrodes X leading from the commutator V, and the direction of these stimuli can be altered by this commutator.

The effects of the currents transmitted by the relay K through the coil can be adjusted approximately by shifting

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the coil R in relation to P, and those from I can be adjusted by increasing the strength of the battery N_2, or by inserting resistances in the circuit. But a more accurate method of adjusting the strength of those currents will be described later.

It is sometimes necessary to cut out the induced current in R at the making of the current in P, or the induced current in R at the breaking of this current. This is effected by the relay L, which is a sort of "rocking shunt." The mercury cups M_1 and M_2 in the relay L are joined by wires to the terminals of the secondary coil R. These are shown by the lines mm. Now let the platinum contact M dip deeply into the mercury while that at M_2 is just clear of it. Let the plugs H_3 and H_4 be withdrawn. It will now be seen that the relay L will act at the same moment as the relay K, and the induced current in the secondary, produced at the making of the current in the primary, will find an easy path between the mercury cups M_1 and M_2, because the platinum-point M_2 will be dipped in at the moment the relay K sends the current through the primary P. But the breaking current will have to pass through the nerve, because the relay L will give at the same time as K, and the point M_2 will be withdrawn from the cup, opening the shunt between M_1 and M_2.

By reversing the adjustment of M_1 and M_2, the "breaking" current may be cut out and the "making" transmitted.

The mode of adjusting the strength of the currents indicated above is sufficiently accurate for demonstration, but is deficient in accuracy for refined research. For this purpose in the bench under consideration, advantage is taken of the principle of the Wheatstone's Bridge.

For adjusting the strength of the Faradic stimulation, the arrangement is as follows:—

The coils P and S (the primary and secondary), Plate III., fig. 2, are placed at a suitable distance from each other. The current from the battery E is sent through the bridge QORX, of which OQ is the wire and X and R are equal resistance coils. The primary coil P is placed in the position of the galvanometer of the bridge, and the circuit is made and broken by the relay K.

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Now, if X and R are equal to each other, and A is in the middle of OQ, then no current will pass through P, and consequently the effect on S will be nil. But, if A be moved ever so little to the one side, then the balance will be broken, some current will flow through P, and a certain effect will be produced in S. The further A is moved from the middle the stronger will be the current in P, and the relative values can be determined for any position of A by the ordinary formula for the Wheatstone's Bridge.

The actual strength of current passing through the primary coil can be read off the milliampéremeter G, which is included in the circuit.

The actual bridge connected with this bench (Plate III., fig. 3) is a circular one. The wire is of platinum-iridium alloy, and is divided into 1000 parts, and the slider is adjusted by a coarse and a fine adjustment—the latter moved by a micrometer screw. The resistances X and R are two sets of coils of value from 1 to 200 ohms each.

By a simple "turn-over" switch the relay I, Plate II., can be connected with the bridge, and galvanic currents of any required gradation can be sent through the nerve at will.

By suitable arrangements the whole mechanism of the bench is under complete control of the observer while sitting in front of the drum and recording apparatus on the experimental table. All adjustments can be made without any assistance whatever, and, save the shifting of the length of the reed, everything can be done without rising from the seat.

The movements of the relays can be controlled at a distance by means of the switch SW, Plate II., which is really a short circuiting key.

This is connected by a pair of thick wires, ww, to the plug F, and can be attached to the experimental table at any distance from the bench. When this switch is closed the current is cut off from the relays which cease acting, while, of course, the action of the spring is not interfered with. On opening SW the current from the spring A will immediately flow through any of the relays whose circuit may be open.

A general view of the bench is given in Plate I.

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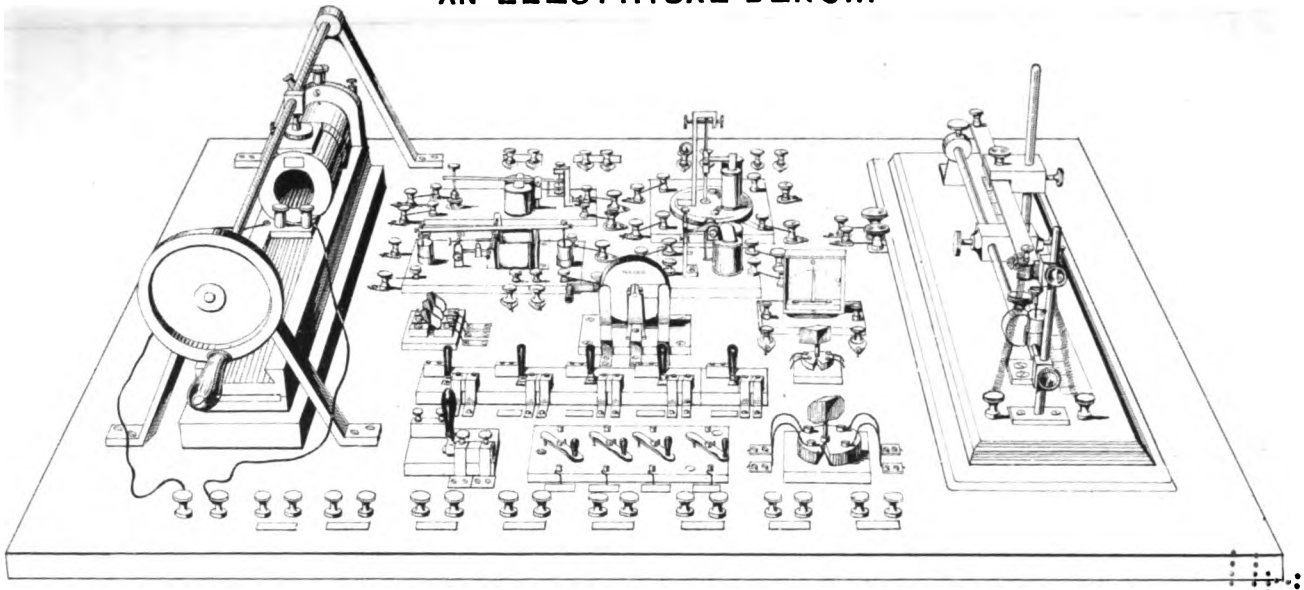
Dr Milne Murray
on
An Electrical Bench.



GENERAL VIEW OF BENCH.

J.T.MURRAY

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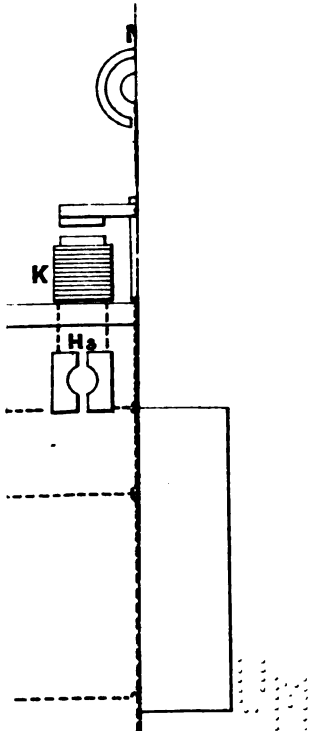

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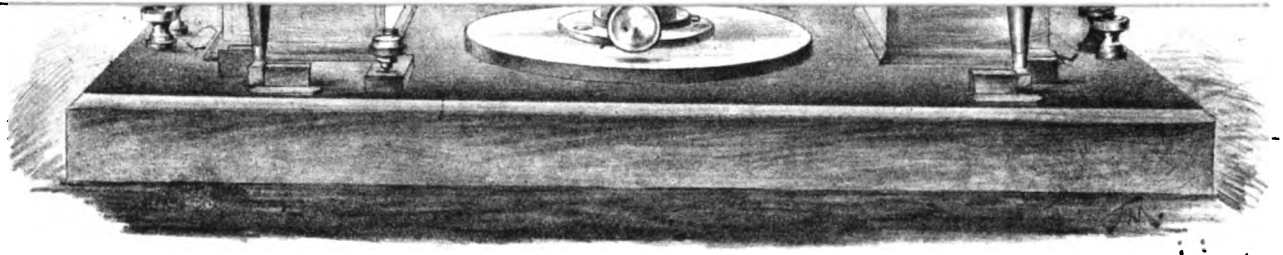

Fig. 3. CIRCULAR BRIDGE.

J.T. MURRAY

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How to Decrease Railway Rates and Increase Dividends thereby. By M. R. JEFFERDS, C.E.

The bane of the industries of the United Kingdom to-day is the excessive charge made by the railways for transporting the products of industry between the producer and consumer. The traders and manufacturers of the whole country are aware of this fact, and have sought relief from Parliament, which body have caused a court of inquiry to be established, known as the "Board of Trade Railway Rates Committee." This Committee have held some eighty-six sittings at an enormous cost, and have now concluded their investigations without examining a single fibre of the root of the disease.

The railway companies have had their experts and solicitors watch every movement of the Committee, and criticise every witness that came before it. When a witness attempted to show the real facts in the case, the solicitors would drop down upon him like a hawk upon an unsuspecting sparrow, and annihilate him at once.

It was the aim of the railway officials to prevent the Committee from obtaining any facts that could be used as a comparison with their own acts and methods, as such facts might lift the veil from the eyes of an unsuspecting public, and show them the deliberate waste of money that is daily being made, jeopardizing the wealth-producing interests of the country to maintain ancient methods and fossilized ideas.

The author was a witness before that tribunal, and was shut out entirely from stating his experience in handling railway traffic, because his experience had been in a foreign country where a different railway system from that practised in the United Kingdom was in vogue. Without a comparison, how were they to judge which was the best for the public? Why are the traders and manufacturers grumbling about high freight rates? By what means do they know that rates are high? Why, by comparison, of course.

A farmer in Scotland desires to send from Stirling Station 30 tons of grain to London market, a distance of 420 miles.

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Under the new classification of rates the freight charges will amount to £57, 15s., plus terminal charges.

A farmer in the State of Illinois, U.S.A., can send from Chicago Station 30 tons of grain to London market, a distance of 1000 miles by railway and 3400 miles by water, at a freight charge of only £47, 15s., which includes all terminal charges and transfers except at London.

This shows a difference of 17¼ per cent. in favour of the Illinois farmer, or, in other words, that Stirling, Scotland, in a trading point of view, is 21 per cent. further away from the city of London than is Chicago.

If the Scotch farmer had the advantage of railway rates even 50 per cent. higher than those paid by the American farmer, his freight charges would be only £19, 13s. 9d., giving him an advantage over the American in the London market of £28, 1s. 3d. on each 30 tons of grain.

This comparison can be multiplied by hundreds of others in all branches of industry, and many of them much more aggravating, whereby foreigners have marked advantages in the markets of the United Kingdom over Her Majesty's subjects, and are protected in them by the railways, whose officials have their backs turned to the future, ignoring innovations, forgetting that the world is going on, and clinging with death-like tenacity to the methods and ways of their grandfathers.

What does such a policy mean? It means death to the industries of the British Isles.

How do we come to this conclusion? By comparing the rates charged in this country with the rates that prevail in a foreign country, making it only a question of time before the industries of the cheapest country will wipe out those of the dearest. Why not also compare, then, the conditions in this country with those that prevail in a foreign country by which so much lower rates are made? Because the railways say "You mustn't." And here we are handicapped and hoodwinked by the very men who should enlighten us most.

The author asserts, without fear of successful contradiction, that railway rates can be lowered one-third, employees paid double the wages they now get, and shareholders larger divi-

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dends than they now receive, by simply entering into an enlightened railway practice, which can be done without calling upon the shareholders for a penny.

The railways of the United Kingdom are by far the best in the world; their freight and passenger rolling stock the most ancient known to railway history, and the cost of handling traffic remains as high as it was thirty years ago. They have held fast to their ancient ways and dozed away in their sleepy picturesqueness, allowing a bustling and giddy world on the other side of the Atlantic, all alive with commerce and ambition and desire for novelty, and the terrible disturbing thing which unresting people call Progress, to rush on its boundless path unheeded, until now the charge made by American railways for moving the products of industry is 37½ per cent. less than the first cost of moving freight in the United Kingdom, and 75 per cent. less than the average rates paid by the producers to the railways in Scotland.

Railways in America have so cheapened the cost of transportation, that while a load of wheat loses all of its value by being hauled one hundred miles on a common road, meat and flour enough to support one man a year can be hauled 1500 miles from the West to the East for one day's wages of that man, if he be a skilled mechanic—and still the Yankee does not think he has yet reached the lowest cost of handling traffic by rail.

The subject of railway rates is one that interests every man in the United Kingdom. The price of whatever he eats, wears, or uses, the convenience with which he receives his mail and the current intelligence of the day, and even the intimacy and extent of his social relations, are all largely affected thereby; therefore every man in the United Kingdom should at once demand a searching inquiry to be made by a Joint Committee of both Houses of Parliament, who should be instructed to make comparisons between our railway system and those of other countries, especially the United States, where the lowest railway freight rates in the world prevail; and if it be found that our system is wrong, enact laws to change it so as to place our internal commerce on an equal footing with other nations, and thus bring into dominant requisition every

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available acre of arable land and every industry in the United Kingdom.

All national wealth depends upon an enlightened and unobstructed agriculture. The agricultural interests of the British Isles are so completely obstructed by excessive railway rates to-day, that a farmer or horticulturist in the interior of the United States, and even at the Antipodes, can successfully compete in the markets of London with the North British and Scotch agriculturist.

Upon the ocean the United Kingdom is the first carrying nation in the world, and has seized every opportunity to extend her ocean empire. From tubs that would carry only a few tons of goods, she has built ships to carry 10,000 tons, and thus minimized expenses and reduced rates, which has in turn increased traffic. But what has she done with her railways that have been built especially for heavy traffic? Nothing.

The railways in America, unlike those in the United Kingdom, were not built for economy in working as freight roads. They were built in the first instance as local roads, with reference to local interests, and not at all as their managers would now locate and build them, to secure and supply adequate means for traffic. They were built on circuitous routes chosen to avoid expense in construction, climbing mountains at difficult and unprofitable grades, and traversing curves that would be impossible with Scotch rolling stock. Far different with Scotch railways. You have uniform grades, easy curves, better alignment, and far better road beds and superstructure than any railway in America, and on top of that you have cheaper fuel, and labour at less than one-half the rates paid in the United States, but at the same time it costs more than double the amount of money to move a ton of freight a mile on your roads than it costs in the United States; and why? Simply on account of the antiquated rolling stock used upon your railways. Stiff, rigid, cumbersome boxes on wheels, that you could not roll round a corner to save your life, and to get them round a curve of the longest radius would be at the expense of excessive motive power, great wear and tear of both the outer rail and wheels, and, if the waggon was not properly loaded, great and undue strain on a single journal, instead of

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the load resting as it should do evenly on all. These waggons have been built from the models first made by Stephenson, with no change in principle and very little in construction. The same principle was taken to the United States in 1831. Their engineers saw that unless vital changes were made their money would not hold out and their roads would be very short. Necessity truly became the mother of invention. Of this Mr Thomas Curtis Clarke, in an exhaustive article upon "The Building of a Railway," recently published in a work by the Hon. Thomas M. Cooley, chairman of the "Interstate Commerce Commission" of the United States, says:—

"The first and most far-reaching invention was that of the swivelling truck, which, placed under the front end of a locomotive, enables it to run round curves of almost any radius. This enables us to build much less expensive lines than those of England, for we could not curve around and avoid hills and other obstacles at will." This truck is what is now termed a "bogie truck," named from a vehicle formerly in use at Newcastle-on-Tyne, having a king bolt or swivel pin to permit of its turning short curves. "The next improvement was the invention of the equalising beams or levers, by which the weight of the locomotive is always borne by three out of four or more driving wheels. They act like a three-legged stool, which can always be set level on any irregular spot. The original imported English locomotives could not be kept on the rails of rough tracks. The same experience obtained in Canada when the Grank Trunk Railway was opened in 1854–55: the locomotives of English pattern constantly ran off the track; those of American pattern hardly ever did so. Finally all the locomotives were changed by having swivelling trucks put under the forward ends, and no more trouble occurred."

The flexibility of the American locomotive increases its adhesion, and enables it to draw greater loads than if rigid. The same flexibility equalises its pressure on the track, prevents shocks and blows, and enables it to keep out of the hospital and run more miles in a year than an English locomotive does.

It would be a simple and inexpensive matter to make a

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similar change upon the stiff and rigid locomotives used in the United Kingdom.

The key to the evolution of American railways since 1831 is the contempt displayed by American engineers for authority, and the untrammelled way in which they invented and applied whatever they thought would answer the best purpose, regardless of precedent.

They made valuable improvements in vehicles both for passenger and freight service, but especially in freight. Instead of the stiff and rigid four-wheeled waggon used in the United Kingdom, which on a rough track dances along on three wheels, they owe to Mr Ross Winans of Baltimore, Maryland, the application of a pair of four-wheeled swivelling trucks with diamond frames, one under each end of a waggon 30 feet long, thus enabling it to accommodate itself to the inequalities of a rough track, and to follow its locomotive around the sharpest curves with little or no more friction than the wheels would have when running on a tangent. There are, on many of the main lines in America, curves of less than 100 yards' radius, while on the Manhattan Elevated Railway, conducting the largest passenger traffic of any railway in the world, there are curves of only 30 yards' radius upon which there has never yet been an accident.

In the United States, as in the United Kingdom, there has always been some dissatisfaction regarding rates. From the very outset attempts were made to regulate railroad charges by law in various ways. The fear at that time was that they might be unreasonably high. This fear proved groundless there, as it would here if Scotch and English railway managers improve their ways and means of conducting traffic.

From the outset in the States the rates were rather lower than had been expected, and much lower than by many of the other means of transportation which railways superseded. The low rates caused a great development in business; and this in turn gave a chance for such economy in handling it that rates went still lower. Each new invention rendered it easier to do a large business at cheap rates. The substitution of steel for iron rails, which began shortly after the close

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of the war, had an enormous influence in this respect. This was not merely due to the direct saving in repairs, which, though appreciable, was moderate in amount; it was due still more to improvement in transportation which followed. It was found that steel rails would bear heavier rolling stock. Instead of building ten-ton waggons to carry ten tons of cargo, they built twelve-ton cars to carry twenty tons, and now to carry thirty tons; and they made the locomotives heavy enough to handle correspondingly larger trains. A given amount of fuel was made to haul more weight, and of the weight thus hauled, the freight formed a constantly increasing proportion as compared with the rolling stock itself. The system of rates was adapted to meet the new requirements. Charges were made incredibly low in order to fill waggons that would otherwise go empty, or to use the road as nearly as possible to its full capacity. In the twenty years following the introduction of steel rails, the traffic of the New York Central Railway increased from less than 400,000,000 ton-miles to 2,775,582,891 ton-miles in 1889, while the average rates fell 76 per cent., or from 1·54d. per ton per mile in 1866 to 0·38d. in 1889, the Company having maintained a high standard of dividends during the whole period. This is but a single instance of a process which has gone on all over that country. The average freight charge on all railroads in the United States to-day, according to Poor's "Manual" of 1890, is but 0·488d. per ton per mile, or 61 per cent. less than the average charge in the United Kingdom upon railways, the poorest of which are as good as the best in the United States, and where the average cost of fuel and labour is less than one-half! It may be said by those opposed to innovations that American roads have thousands of miles' haul. Such is not the fact. The average haul during 1889 was only one hundred and ten miles. The average haul is less now than it was five years ago, and seems to be getting less as rates are reduced.

The following table will show a comparison in working expenses between the New York Central, without regard to higher-priced fuel and labour, and two of the favourite Scotch lines.

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Working Expenses per ton per mile.	N. British Railway. Penny.	Caledonian Railway. Penny.	New York Central. Penny.
Maintenance of way, works, &c.,	0·0983	0·0862	0·0411
Locomotive power (including stationary engines),	0·1505	0·1452	0·0696
Repairs and renewals of carriages and waggons,	0·0614	0·0717	0·0264
Traffic expenses, coaching, and merchandise,	0·1934	0·1772	0·0779
General charges,	0·0225	0·0273	0·0041
Rates and taxes,	0·0249	0·0317	0·0138
Government duty,	0·0036	0·0033	0·0001
Compensation for personal injury,	0·0013	0·0032	0·0019
Compensation for damages and loss of goods,	0·0030	0·0027	0·0010
Legal and Parliamentary expenses,	0·0033	0·0073	0·0010
Steamboat, harbour, and canal expenses,	0·0183	0·0127	0·0126
Miscellaneous,	0·0130	0·0212	0·0079
Average working expenses per ton per mile,	0·5935d.	0·5897d.	0·2574d.
Average charge per ton per mile for moving freight,	1·25d.	1·25d.	0·38d.
Percentage of working expenses on gross receipts,	47 °/₀	47 °/₀	66·42 °/₀
Number of tons moved,	15,635,420	16,808,781	16,426,504
Total earnings,	£2,967,617	£3,201,100	£7,360,000
Total number of locomotives employed,	1046	871	919
Average annual earnings of each locomotive,	£2,837	£3,500	£8,008
Percentage of minerals moved (usually carried in full loads),	74·89 °/₀	77·23 °/₀	29·65 °/₀
Percentage of goods traffic (usually carried in less than full loads),	25·11 °/₀	22·77 °/₀	70·35 °/₀
Dividends ordinary shares,	3½ °/₀	4 °/₀	4½ °/₀
Average number of tons carried per train mile,	...	...	226
Average number of waggons in freight trains,	...	...	37
Average load carried per waggon,	...	...	6·2 tons

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TABLE SHOWING SERVANTS EMPLOYED AND COMPARATIVE AVERAGE WAGES PAID ON THE N. Y. CENTRAL RAILWAY AND IN THE UNITED KINGDOM:—

	New York Central.	Average in the U. K.
Number of servants employed,	20,944	
Average wages paid per annum:—		
General office clerks	£165	£ 80
Station agents	141	85
Telegraph operators	114	52
Other station men	118	...
Engine drivers	250	117
Stokers and wipers	132	78
Guards	206	75
Other train men	129	52
Mechanics and helpers in shops	123	...
Other shopmen	95	...
Roadmasters and track foremen	125	...
Other trackmen	91	...
Switchmen, flagmen, watchmen, &c.	97	...
Mechanics and helpers, road, &c.	138	65
Employees on floating equipment	153	...
All other employees	152	...

From the above it will be seen that had the Scotch roads referred to worked as cheaply as the New York Central, the North British would have saved 56·60 per cent. and the Caledonian 54·35 per cent. in their working expenses, to say nothing of the saving that could be effected by their now having cheaper fuel and cheaper labour. Now the question that arises is this: If the New York Central pay so much more for fuel and labour, how is it that they work at so much less cost than the Scotch railways? The author's answer is that the New York Central Company use more modern machinery in conducting their transportation; that the Scotch roads are working as economically as they can do with the appliances they have at hand, and that before they can reduce their working expenses to the satisfaction of their employees and of the public they must adopt modern appliances such as have proved to be economizers in other countries.

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The question now arises, How can this be done without an enormous expenditure of capital? The author's answer is, Stop building new waggons of the ancient type. Whenever two old waggons come in for repairs, if the repairs exceed five pounds sterling, take their wheels and axles, if good, and put them into swivelling trucks under frames that are strong enough to carry 40-ton loads, but load them to only 15 or 20 tons. When the old wheels are worn out, new wheels and axles with larger journals can be substituted, so that maximum loads of 40 tons can be carried; all of which could be done with the money that is now being expended for repairs and renewals; and it would not be many years before the present type would be extinct, and the railways placed in a position where they could compete with the world. The change would enable these railway companies to reduce their rates one-half, which would quadruple their tonnage, and not only pay shareholders larger dividends but pay employees larger wages than they now receive. It would be the means of quickening every industry throughout the land, and giving employment to the present surplus labour.

The author thanks the Association very much for their kind attention, and hopes that the ideas advanced and the statements made may be thoroughly investigated by all the members, that they may know for themselves "how railway rates can be reduced and dividends increased thereby."

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JUBILEE DINNER OF THE SOCIETY.

On the 2nd of November 1891, the Fellows celebrated the attainment of the Jubilee of the Incorporation of the Society by a dinner which took place in the banqueting-hall of the Waterloo Hotel, and at which upwards of 140 gentlemen attended. The Right Hon. Lord Kingsburgh, President of the Society, occupied the Chair, supported by Lord Provost Boyd and representatives from other scientific societies and public bodies; whilst Messrs R. K. Miller and W. B. Blaikie, Vice-Presidents, and Mr W. Allan Carter, Secretary, acted as Croupiers.

After dinner, the toasts of the Queen and of the Royal Family were duly honoured. The Chairman then proposed "Prosperity to the Royal Scottish Society of Arts." It was now fifty years, he said, since Her Majesty had granted to the Society its charter of incorporation, and every one who knew the history of Edinburgh knew that the Society had taken a worthy place within its organisation, and had done much good in the encouragement of invention and of art; and their best hopes would be that in the coming fifty years it might do its duty as well as it had done in the past. The late Dr Edward Sang had been one of the members of the Society who, from its earliest start, had given his time and his energies to make it a success, and the Chairman paid a high tribute to the devotion which Dr Sang showed in furthering its interests. He also, on behalf of the Society, welcomed Mr Lawrence Hill, who was present at the jubilee

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celebration, and who was one of the few gentlemen still remaining who were members in 1841. He went on to speak of the special function of the Society, which was not one of those in which nothing but abstract science was allowed to enter. It was a practical Society, and its history showed plainly that it had been of the greatest possible benefit in bringing before the public many valuable discoveries, and had tended to promote progress in many ways. In looking over the *Transactions* many things had come under his notice which showed the changes which had taken place in the last fifty years. One thing which he had noted in the first volume of the Proceedings of the Society was a paper by the late Mr David Stevenson upon one of the railways of England, in which Mr Stevenson recounted some things which at that time were thought very extraordinary. One of the things mentioned for the information of the Society was the extraordinary fact that the locomotive department of that railway spent the enormous sum of £28,000 in one year, and that the engines were driven by a driver with the aid of a fireman. "As a check on their regularity," the paper went on, "a fine of 2s. 6d. is imposed on the engineer for every fifteen minutes he arrives before his time." The Chairman said he thought we had made no progress in that particular matter since 1841. He went on to point out how, in looking over the *Transactions*, he had been struck with the fact that in this year, 1891, we were very much in the same position as regards the development of one branch of practical science as the Society stood in 1841 as regards another. In 1841 the Society was

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just in the very first blush of the enormous development of steam-power; and it appeared to him that at its jubilee celebration it was very much in the same position as regards the development of electrical science. It was very difficult for any mind, however instructed, to conceive what the progress was that might be made within the next ten or fifteen years in the development of electrical science; just as in 1841 none of them could have conceived the development of steam-power, and the extraordinary effect it would have upon communication between different parts of the world and upon the power of manufacture and interchange between different countries. It might be that they were just upon the verge of another development as extraordinary and perhaps as inconceivable, and it would be a proud thing for the Royal Scottish Society of Arts if it could lend its aid to the inventors of our time to help them forward in the development of what undoubtedly was one of the great things of the future. He had no doubt that the members of the Society would give their earnest help to all who were engaged in investigating that important matter. The gathering of that evening was the best proof that the Society had been prospering; and he asked all of them to devote themselves earnestly to promoting its best interests, being sure that in so doing they were promoting the best interests of science and enabling many struggling inventors to gain that recognition for their work which otherwise they might not be able to do.

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TRANSACTIONS

OF THE

ROYAL SCOTTISH SOCIETY OF ARTS.

On Tynecastle Embossed Canvas. By W. Scott Morton, R.S.S.A.*

As a preface to a few notes about the Tynecastle Canvas, I might refer briefly to decorations in leather, because it happened that when the inventor was working at imitations of old leather, the idea of the modelled canvas suggested itself.

In the early part of the fifteenth century, embossed and stamped leathers were used as carpets for floors; and, about the same time, "Cordovans," which were leather hangings, were produced at Cordova in Spain. These leathers were originally painted with some uniform pattern, and enriched with a design formed by pressure from a hot iron against a roller. They were made in squares for wall surfaces of different sizes, and were sewed or glued together, and narrow strips of leather were fixed over the joinings.

Soon afterwards, picked-out colour effects were introduced, and very decorative and gorgeous displays of colour were obtained by the use of metal leaf gildings, which were commonly of silver. On the silver gildings golden tints were obtained by the use of varnishes.

In the inventory of Catherine de Medicis there is given an idea of the richness of the leathers of her time. There are mentioned "gold and silver hangings on an orange ground with the Queen's cipher; others again sea-green, with mountings similar to the preceding; others with orange mountings, gilded or silvered, on a violet ground: or else red with gold

* Read before the Society, 23rd November 1891.

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and dove-coloured mountings; blue with gold, silver, and red mountings, not to speak of the multifarious mourning hangings, in which the background is relieved by silver alone."

In Italy, at the end of the fifteenth century, white oxhides were prepared for bed hangings, to the order of the Queen of Charles VIII., and this led to the production of that kind of work in France by Italian painters, and was continued there till the early part of the eighteenth century. There are examples of this kind of work in sheepskin, from an old house in Rouen, in the Cluny Museum. The designs seem to have been chiefly figure subjects, worked and stamped with dies, and decorated in colours, while the grounds were gilded.

Early in the eighteenth century a wider and bolder development of leather work appeared. The bold relief was obtained by the use of wood moulds, into which the leather was pressed when in a state of heat. This widened scope in working demanded free designing, and great variety began to show itself. This handsome decoration became the product of several important centres, such as Venice, Flanders, Paris, Lyons, Carpentras, and Avignon. Wherever the influence of the Renaissance was felt, this effective means of decoration was adopted, and, in the time of the decadence especially, much of this kind of work was done in Holland; but in a period of artistic laxity, when an effective and costly decoration becomes fashionable, there is a temptation to imitate it in a cheap, showy fabric, and we find that in France and England printed papers were introduced in imitation of leathers. Soon after this, Flock was introduced in imitation of cloth or tapestry, and an example is on the table which I got at Antwerp of embossed and gilded leather with flock printing over the gold.

In Germany, Frankfort, and Worms, papers were manufactured in high relief embossings, in imitation of leather hangings. These have been more or less in demand since their introduction, and in our own time many productions of this class are in the market.

The Tynecastle Canvas, as far as my knowledge has extended, is quite a new departure in wall decoration. The canvas texture was desired, because of its artistic value, and

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the canvas fabric commended itself as being a sound and inexpensive one.

The story of its inception may be told in a few sentences. In the development of a decorative furniture concern the need was felt of a ready means of expressing original designs in relief work for the walls of apartments, and just then an elderly man applied to me for employment in any kind of work in which he could make himself useful. He had been employed in Edinburgh for some years, chiefly in picture mounting. On questioning him as to previous occupations, I found that in London he had done a little in the working of leather enrichments, in imitation of flowers, for picture frames, furniture, and cornices. The mention of his leather-working experience encouraged me to give him employment, and a start was made by the modelling of a leather decoration for the background of cabinet recesses and covings. The pomegranate formed the subject of the pattern, and one is reminded of this early effort by an occasional visit to the Grosvenor Gallery, where it fills some panels in the large saloon.

Immediately after the introduction of this work, when one day in London, I was asked by Lord Cadogan's architect if I could help him over a difficulty which he and Lord Cadogan were experiencing in regard to the completion of the wall-covering of the library of his Lordship's mansion in Cadogan Square,—the circumstances being that a quantity of old leather which was purchased for these walls was insufficient, and more of that design could not be found. I asked if I could see one of the old skins. One was shown to me, and on examination I felt convinced that facsimiles could be produced, and I undertook to complete the room. In a few weeks afterwards the embossing and old effect of colouring were satisfactorily accomplished, and the walls were covered with the old and new leather skins side by side.

The commission to enlarge and embellish a house in Park Terrace, Glasgow, for Mr Alexander Stephen, was entrusted to me at that time; and, as there was a feeling after a something modelled with a texture which would give subtilty to ordinary colour methods, more than any smooth surface could afford, the idea of using a woven fabric suggested itself. I

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set my leather-working protégé agoing with woven material, and after many experiments a linen canvas, woven loosely, was found to give the effect that was wanted, and the dining-room at 12 Park Terrace was decorated with the first specimens of the Tynecastle canvas. A leading decorator in London was then on a visit to Edinburgh, and, having seen the new decoration, ordered it for a library in Grosvenor Square. There it attracted the attention of the Duke of Westminster, who visited the house. The Duke afterwards requested his own decorator to obtain the new material for two of his picture saloons at Grosvenor House. The Duke told him only two things about this new wall covering,—viz., that it was embossed with a canvas texture, and that it was foreign. The idea of its being foreign set the decorator searching all over the Continent for what was wanted, and, as he afterwards told me, he had to give the matter up. The Duke then went to the house where he had seen the canvas, and got the name of the man who fixed it, and gave him the commission to complete the rooms. When the disappointed decorator made my acquaintance, he told me the story of his commission and fruitless search, and said that it never occurred to him to try the foreign country of Scotland.

After such a favourable introduction into the Metropolis, much interesting work soon followed, and, as may be imagined, orders for London and for other parts taken in London form the best part of the Tynecastle Company's business.

In the working of the modelled canvas, the all-important consideration was so to emboss as not to lose the texture. This essential point precluded the adoption of back moulds, which are so commonly used for relief work. These would cause the canvas to pucker, and the amount of pressure required would destroy the artistic quality, and give an appearance of milled work. Generally, it may be stated, that the way in which the canvas is worked is by gathering in a larger piece of cloth than would cover the block or rollers until all the depressions in the moulds are covered by it. This is done by gentle pressure of the canvas, while wet, after it has been boiled, small tools and brushes being used by the worker in the process. After the canvas is all gathered in

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and fitting closely to the matrix, it is strengthened by the application of a specially-prepared paper, which is softened and beaten in by hand with brushes, and fixed with paste. The application of the paper not only strengthens the design, but it also enables the fabric to behave well in the process of fixing to walls. The tendency of pasting by the paperhanger is to swell paper and contract canvas, so as the two materials are fixed together: in the Tynecastle fabric the hanging is always satisfactory if the pasting is not allowed to be done more than fifteen or twenty minutes before fixing.

The slowness of the process of hand-modelling seemed to be a great drawback in the development of a business, and a machine was invented and patented for quick production. The principle of this machine is simply this, that along a horizontal line on the surface of a modelled matrix cylinder there is a series of spring stampers, with soft india-rubber pads, and so arranged that only one pad presses at one spot at one time.

It soon became evident that higher relief would be desirable to meet the requirements of the growing business, and this was tried by the same process adopted in flat work, only some stiff backing was used; but the shrinkage that took place in drying presented a great drawback. In low relief work this occurred to a small extent also, but the pasting necessary for hanging obviated any drawback on that score. In the higher relief, however, the hardening of the thick backing was found most troublesome in fixing, as it was impossible to get the perfect flatness required for good work. This difficulty led to experimenting, which resulted in a process which was patented, and has answered perfectly. The principle of this patent for high relief work lies in the application of heat to the canvas, after it has been modelled, to give it a true set; and when quite set, a thin composition is pasted over the back of it, with an extra coating or two where the relief is specially prominent. The backing paper is then applied, and after all is thoroughly dry the work is complete. The moulds in this process are always of metal.

In small designs, plates are adopted, which at a certain stage are placed upon a hot table; but for very large and bold designs, in which the matrixes could not be handled, except

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with great risk and trouble, the mould is made to form the lid of a chest. In this case the canvas is modelled when the matrix is cold. This being accomplished, there is a volume of steam, at 4 lbs. pressure, let into the chest, and the lid or mould being of thin metal the whole surface is soon heated, and the backing is proceeded with, as before described, after the canvas is set. When the drying is almost completed the steam is shut off, and a volume of water is run through the chest to cool the mould for receiving another cloth.

This process having proved successful, a patent was obtained for the application of the same principle to rollers, as it was found that by quick working the canvas could be modelled in flat relief while a cylinder, heated by a low pressure of steam, was revolving.

One great advantage which the hot chest process gives is the large scope of design. The chests at present in work afford, by working them in pairs, an opportunity of planning a pattern 9 feet long by 5 feet wide. There could be larger designs, but commercially there is no call for them.

For exceptional work, special moulds, of course, can be produced, such as curved work for domes, covings, and deeply recessed panels.

The question very often arose, when new houses were in hand, as to the best ground on which to fix the Tynecastle canvas work, and two coats of plaster were recommended, left with a roughish texture. But it appeared that in much work where ornamentation was required, what is called fibrous plaster was being freely used. This, as most know, is produced by the pouring of stucco into moulds, with a layer of scrim embedded in the stucco while it is wet.

This fibrous plaster idea was taken advantage of, and a patent was applied for recently for slabs, with the Tynecastle modelled canvas on the face and a plaster back. The large example in the room will show you part of a ceiling which is being produced for the hall of the St Andrews Students' Union, of which Dr Rowand Anderson is the architect. One of the great advantages the Tynecastle canvas possesses is that slabs of it can be prepared and finished in gold and colours, ready for screwing up to ceilings, friezes, or walls

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against groundings of wood planned to receive them. This is a great advantage in large cities, especially where time in altering interiors or in finishing new buildings is of great consequence, and the finished decorated effects are in no danger of damage from wet plaster.

On Destructive and Conservative Distillations of Mineral Oils and their Molecular Condition. By JOHN LAING, F.I.C.* (With Four Plates.)

The subject I wish to bring before you this evening is of a twofold nature, the one being distillation of a destructive character and the other of a conservative character. Mineral oils, treated by the former method, are broken down into lighter products, but by the latter method it is intended to retain the full body of the oil and prevent its being broken down.

For several years past I have devoted a considerable attention to the subject of destructive distillation of mineral oils, and I thought it would not be uninteresting to the members of the Society that I should bring the subject prominently before them, more especially as this Society has for its object the encouraging and promoting of invention and improvements in our industries, as well as in all connected with science and art. Till within the last few years very little work has been done, comparatively speaking, in breaking down very heavy oils into lighter ones; but the subject now is ever increasing in importance, and I may safely say that it will not be long before we have a fair practical knowledge of the subject on a large scale.

Both on the Continent and in the colonies there are unlimited supplies of natural oils of all grades and qualities. Some of them like the American, very low in specific gravity, and others like the Russian, very heavy, whilst we have all intermediate grades. In a country like Russia there is any amount of outlet for burning oils, and as the bulk of the

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* Read before the Society, 14th December 1891.

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natural oil found there is very high in specific gravity, and the percentage of burning oil obtained therefrom is very small by ordinary fractional distillation, a process of destructive distillation which can be carried on with economy in working, and safety to life and property, must be of the greatest importance to that country, as well as to others similarly placed, and every day brings the demand for such a process more prominently to the front.

When mineral oil is being manufactured, as in this country from shale, it is of the utmost importance that all vapours should be removed from the retort as soon as formed, and that removal should be conducted at as low a temperature as possible, for, if the gases have a long travel through a very high temperature before they leave the retort, they get split up and degraded to a wonderful extent, the high melting-point paraffins get reduced, the low melting-point paraffins get split up into liquid hydrocarbons; the heavy lubricating oils get degraded into those of less viscosity, and what would form the burning oil portion gets split up into naphtha and permanent gas. I will now give you an illustration of this breaking down.

In my various experiments I was very much struck with the behaviour of certain oils, and also of the same oil under treatment of refining; for instance, I found I could not get the same results from one individual crude oil when distilled under slightly different conditions in its various fractions. For example, I found that in distilling, say 20,000 grain measures in 5 per cent. fractions in my usual still, I got certain results; but if I took 5000 grains of the same oil and distilled that quantity under the same conditions in the same still, and took it off in 5 per cent. fractions, on comparing the fractions in both cases I did not get them to agree, the oil in the latter case being very much split up. Taking another 5000 grains of the same oil, and distilling it in a smaller still, the capacity of which was one-fourth of that of the large one, I got the fractions to correspond more nearly; the setting points, viscosity, and gravity of the various fractions were nearly the same as the distillate in the larger still.

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I tried another experiment with the larger still, in the one instance, using wide delivery tubes, and in the next distillation I used very narrow or small bore tubes, and I found I got a degraded oil in this second distillate, which corresponded, in a degree, with the distillate of the small quantity in the large still. I then fitted up another set of delivery tubes, having a stop-cock arrangement so that I could regulate the outflow of the gases from the still, and I found that I could obtain results very different from anything I had yet got, according as I left a smaller or larger aperture for the gases to pass. I tried yet another experiment in a larger still with wide delivery tubes, but in this case I fed the still at the same rate as the distillate came off; in other words, I kept the still, as nearly as possible, at the same level, and I found that I got the best results by far of any of my former distillates. The smell was sweeter, gravity higher, paraffin of high melting point, greater in quantity, and the viscosity of the lubricating oil much higher, and the corresponding loss was less.

The conclusions I came to were that radiant heat was the cause of the degraded condition of the resulting oils, and that also pressure might assist this breaking down, for when I restrained the flow of vapours from the still it naturally put a back pressure on the still. Pressure, pure and simple, without distilling heat, does not affect the oil. You may put on a pressure of 200 lbs. per square inch in your still, and keep it at that for twenty-four hours, and your oil will be unchanged. If you take a high boiling point oil, say over 500° F., and heat up the contents of your still within its distilling point, ever so little, say to 500° F., and let it remain locked up under 150 lb. pressure per square inch, so that no vapours can possibly escape, and leave it so for twelve hours and let it cool down, you will find that the oil has changed very little indeed; the invisible molecular energy caused by the applied heat had not reached that point which was necessary to force the molecules so far apart as to break down the compound molecules.

What action, then, has pressure on an oil when distilled under its influence? It is simply this:—It raises the boiling

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point, and thus necessitates the entrance of more heat into the oil for its evaporation, and the energy of this extra heat assists in breaking down the cohesive attraction of the compound molecules of which the oil is built up, and at the same time it keeps the gases in the still longer under the action of the radiant heat from the sides of the still above the level of the liquid inside; and as these sides, or portion of the still, allow more heat to enter the still than the bottom portion covered with a deep layer of oil, which is a bad conductor of heat, the gases held there by the pressure are constantly being split up, and lighter products formed. It is just a question of time; if you fire heavily, and bring away the vapours as fast as formed, you will get a heavier distillate than if you fired slow and kept your heat just high enough to evaporate your oil slowly. If you keep these vapours a lengthened period in contact with the upper portion of the still, the radiant heat will soon split them up, and a lighter distillate will be the result. If you take a works-still running heavy oil and paraffin, and for some reason or other the distillation had to be stopped and fire drawn, when you again fire up and commence distilling you will not get the same products at start as you left off running at, when the still was damped down, you will always get light spirit or naphtha at the start, and all the distillate to the end will be of a degraded character. Your solid paraffins have suffered, and the viscosity of your lubricating oil has got thinned down considerably. This is partly due to the oil vapours or compound molecules remaining in contact with the hot sides of the still above the liquid portion, and there getting broken down, falling back into the still, and getting condensed, are ready to come off at a lower heat when the fire is again put on, and yield a product of lighter specific gravity. It is upon this principle that "cracking stills" at present in use are worked. The method employed is to have a high upright still, and conduct the distillation so that the heavier vapours rising up in the still will fall back again, and get condensed and re-distilled or evaporated. Of course, no steam must be employed in this distillation, else it would carry over the vapours from the still and prevent their remaining long enough to get broken down.

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This method has never been considered very satisfactory; the distillation is extremely slow, and large quantities of the lighter vapours get converted into permanent gas. What does all this point to? It shows us that there is a limit to which we ought to allow our stills to be fired when working for heavy oils. When distilling for lubricating oils, get your gases out of your still as fast as possible; arrange your flues connected with the furnace so that the top portion of your boiler still is protected by being, to a certain extent, shut off from the hot gases from the combustion chamber. You will thus minimise the area where excessive radiant heat would do the most harm to the oil vapours; on the other hand, you must not have your still top too cold, as it would act, in a degree, as a condenser, and the heavier vapours falling back into the still would get split up by being re-evaporated. Have as free an outlet as possible from the still, and that not too high from the boiler top. I would strongly recommend an exhausting arrangement be fitted to each still for "heavy oils and paraffin," so that the vapours would be more quickly removed and thus a lower temperature would be required to distil the oil than by the present method of distilling. Various opinions have been expressed as to the molecular condition of mineral oils, but none of them have been satisfactory to my mind. My own opinion is that mineral oils are made up of compound molecules of various sizes, and according as these compound molecules are large or small, so is the oil heavy or light, and it is the breaking down of these compound molecules into compound molecules of a smaller size which constitutes what is technically known as the "cracking" of oils. (I will have a few words to say on that subject further on.) The oftener you distil a mineral oil you make it the lighter, and although you may begin with a heavy oil your first fractions in distillation will always be comparatively lighter than the fractions which built it up; and if you go on distilling this oil, over and over again, and so breaking it down, you will gradually come to very light material, which soon gets split up into permanent gas, and all you have left is a little carbon at the bottom of your still. There has always been a difficulty in obtaining a distillate of uniformly low specific gravity

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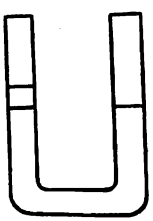
throughout, without entailing too great a loss through permanent gas, and it is greatly to overcome this difficulty that I have devised the apparatus before you. By referring to the diagrams you will see the internal arrangements of the same.

It consists of a divided boiler, whose compartments do not reach the bottom. This allows a free way throughout for its contents. Thus, the still when first charged will stand with all its compartments at the same level with oil. On the top of the still is a series of condensers, arranged so that the gases from the first compartment pass over, get condensed, and fall into the second compartment; then the gases from the second compartment pass over, get condensed, and fall into the third compartment, and so on to end of the still, where they finally pass over by the swan neck leading to the main condenser in connection with the general receiving tank. In using this apparatus, the greatest heat is to be applied to the end compartment furthest from the swan neck, and it is tapered off gradually towards the opposite end. Some may be inclined to think that because there is a freeway all along the bottom of the still, that the contents will heat up uniformly *en masse*, but this is not the case; heat currents have always an upward tendency—never a transverse one from their first source —and as you have a graduated heat under the still, so each compartment has a corresponding difference in temperature.

I will show you this by a very simple experiment. Here is a glass tube bent so that one leg rises from a lower level than the other, *i.e.*, the two upright legs rise from an oblique base; in other words, the legs are parallel, but they are not at right



angles with the base. Fill this tube three-quarters full of water, and of course it will stand at the same level in both legs; but now let us apply heat to the highest point of the base, and you will find that the water will actually boil in that leg while the other remains comparatively cool; not only so, but you will find that the water has increased in bulk in that boiling leg. If you now apply the heat to the opposite end of base, keeping the lamp just sufficiently

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inwards to clear the upright leg, you will find that the heat currents will pass upwards along the base, and up the far off leg, rather than take to the nearer one, simply because they would have to force themselves downwards to arrive at the nearer leg—the natural tendency being upwards. We are accustomed to say that "water gains its own level." We ought to qualify that statement by saying "water of *uniform temperature* gains its own level."

Now let us follow what takes place when breaking down an oil in the form of still before you. I have already pointed out that the oftener you distil a mineral oil you make it the lighter. Well, the oil in the first compartment boils first, the vapours pass over, get condensed, and fall into the second compartment. This oil, which has now fallen into the second compartment, is lighter than the body of the original oil in first compartment, and hence it requires less heat to re-evaporate it; it here meets with that less heat, and it is again redistilled into the third compartment, always getting the lighter at each distillation into each succeeding compartment, till finally it leaves the still. If you wish to bring off an oil of uniform specific gravity, you only require to keep your finishing compartment at a correspondingly steady temperature. For instance, if you wish an oil whose boiling point is 250° F., you must have your last compartment kept steady at that temperature, and no oil can possibly come over whose boiling point is higher. In order to better regulate the temperature of this last compartment, I have arranged a water jacket attached to it, with an inlet for cold water at the bottom, and an outlet for the hot water at the top; the more cold water you run through this jacket will necessarily keep the end compartment the lower in temperature, and by this means you have a power of regulating the distillate to almost any gravity you want. If you try to overfire, you only increase the speed of the distillation into itself, and the cold oil constantly running from the condensers into the still guards it from harm. The still can be fed continuously, and I have made provision for the removal of residues in their most valuable form. In some cases, as in Russian oils, the unvolatilised residue, although liquid whilst hot, hardens on cooling into a pitch of

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first-rate quality, and in order to arrive at the proper point at which this can be obtained in the best condition, I have arranged a sampling vessel by which a small quantity can be run off, at any time, from the still bottom with perfect safety, and examined from time to time before running the bulk to the pitch-pit or tank. (A working model is before you on the table.)

Radiant Heat

Is a very powerful agent in breaking down oil vapours (see Plate No. 2), and if properly applied can be used with advantage. I have devised a method for its use, so that by simply passing the gases as they come from the still through a superheater exposing a large area of heated surface for the gases to pass over, they will readily get broken down and yield a lighter distillate according to the area, the temperature of the superheater, and the length of time the gases are in contact with it. The diagram explains the arrangement, and shows the connections from still to condenser, and also flue arrangements for the regulation of the heat.

The syphon trap at the end of the condenser will always ensure an oil-seal, and prevent any atmospheric air from passing to the superheater; this may be quite unnecessary, but I use it as a protective measure. It also shows arrangement for connecting the still with a vacuum pump; the discharge end of syphon would have to be lengthened, and dipped into the oil according to the amount of vacuum to be balanced.

Distilling under Pressure

Is another method by which this breaking down can be accomplished (see Plate No. 3). Two methods have been employed to do this, but both of them carry with them such great defects that little has ever been done with them. One of these methods was to place the pressure valve direct on the swan neck from the still, and connect it direct to the condenser; but the vapours, under pressure, as they escaped from the still, rushed with so great a force through the condenser that a very large quantity escaped into the air uncondensed—this meant loss and risk from fire.

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The other method was to place the pressure valve at the end of the condenser coil, but here we have practically the same results, for, when the oil under pressure escaped from the valve, it came away surcharged with gas, like an aerated water when the cork is drawn, and that meant loss of material as well as risk from fire, and not only so, but all your fittings being under pressure could not be kept tight through the expanding and contracting action which was always at work.

The method I propose to employ gets over all these difficulties, and that in a very simple way. I place my pressure valve on the direct outlet from the still, and when the desired pressure has been overcome, the gases immediately escape into a large iron box surrounded with cold water, which acts as a condenser, and the pressure is here distributed over such a large area that it is practically reduced to *nil* (*i.e.*, to atmospheric pressure). What condenses here runs out by an outlet at the bottom of the relief tank (as I will hereafter call it), and escapes at once through the condenser to the receiving tank; and what does not here condense rises up and over by an outlet at the top of the relief tank, and goes direct to the condenser, where it meets the condensed oil from the relief tank, and is condensed and run to receiving tank in the usual way. You will thus see that I get quit of all pressure immediately the gases leave the still, and by interposing this relief tank I am able to keep a hold of all the gases till they are condensed into liquid products, and the fittings are relieved of all pressure and remain tight.

Before proceeding with the conservative method of distillation, I would like to say a few words in further reference to the molecular condition of mineral oils. I conducted a number of very interesting experiments (which I need not trouble you with here), which led me to the conclusion that the molecular condition of mineral oils took the form of aggregated molecules, whose affinity for each other was very great, and these I have called compound molecules. Of course, they are of ultra-microscopic magnitude. These compound molecules are of different sizes, and in proportion as these are large or small so is an oil heavy or light in specific gravity. The cohesive force, by virtue of which its compound molecules are held together, is not the

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same in all mineral oils of the same specific gravity. Some oils are more readily broken down than others. To put it popularly, they appear to me to keep together just like members of families; the larger the families you have together you have the denser oil, and according as you have a number of smaller families mixed through with the larger ones so you have oils giving light and heavier products in distillation. If you have a number of large families of stout and strong constitutions together, you will have a body capable of resisting a great amount of external force; in other words, you will have an oil which will not be readily broken down. If you have a number of large families together, and constituting an equally heavy oil as the other referred to, but the families are of a comparatively weakly constitution, it will take a less force to break them down, and here you will have an oil which is easily cracked up; the cohesive force has not been so great as in the other instance here referred to. In short, the compound molecules break down in proportion as this cohesive force is overcome; and, if you push this force to the extreme, I have no doubt you will at last rupture the chemical affinity, and your ultimate molecule will be broken up into its component parts, hydrogen and carbon, the former escaping as a permanent gas, and the latter being left behind in the still: the great heat or force employed unties the bond of chemical affinity and liberates the atoms. I have now come to the last heading of my paper, viz.—

The Conservative Distillation of Mineral Oils.

From what I have said before, you will readily understand that if we wish to obtain an oil of maximum density and viscosity, we must distil it at as low a temperature as possible, and as quickly as possible, so that the oil vapours be preserved from being broken down by being kept too long in the region of great heat. Even in the most approved system at present of distilling mineral oils, we have not got over the difficulty which meets us when distilling for lubricating oils of high density and viscosity.

I have long been under the impression that we obtain far too low a percentage of these high density oils from the crude

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material we start with, and I think I have taken a step in the right direction in bringing before you, for the first time, this new form of still. Before describing the apparatus in detail, I think a few words of explanation as to the advantages to be gained by this form of still over those at present in use will not be out of place. In distilling mineral oils as at present, the contents of your still are gradually getting the denser as you proceed, and by the time you are three-fourths through with the distillation you have a very viscid material to deal with, and this, from its non-conducting properties and density, has a great tendency to cling to the bottom of the still and prevent the necessary heat passing to evaporate it quick enough, and hence you require to force more heat into the still to overcome the resisting action of the thick residue. In this way the sides of the still, above the level of the oil inside, get excessively heated, and the oil vapours coming in contact with this radiant heat are very apt to get broken down to a considerable extent, and thus yield a degraded distillate. If you pump in fresh oil on the top of this heavy residue, I find this oil does not, to any great extent, dissolve the residue in the still, but lies on the top of it; and while this latter portion is being distilled, a granular pitch is being formed at the bottom of the still, and if you push your heat further you will convert this gradually into coke of a very hard nature, and you will have a considerable loss through the formation of permanent gas.

I have seen this very beautifully illustrated on taking off the end of a horizontal still I was working with. The layer of coke next the skin of the still was exceedingly dense in character, and it gradually got less dense as it increased in thickness, and towards the upper surface it was quite granular, and this again was topped with a pitch which remained plastic on cooling. You will thus see that practically all the heat which was distilling the oil on the surface was obtained from the upper sides of the still, and not from the bottom—very bad economy of heat indeed. This excessive heat at the end of the distillation is the main cause of the short life of many of our oil stills.

With regard to this new form of still which I have the honour

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to place before you (see Plate No. 4), I think I have surmounted these difficulties. You will observe that in vertical section it takes the form of a cross, ┼, the head of which forms the attachment of the Swan neck; the wings forming the distilling chamber, and the tail-piece being that portion by which the pitchy residues are kept separate from the lighter oil under distillation. By means of a ball-cock arrangement, the still is kept always at a uniform depth. The heat is applied to the under surface of the wings all round the still, and as this distillation goes on, the heavy residue, which forms, gradually finds its way to the bottom of the tail-piece, and remains there away from the source of heat, and when sufficiently heavy can readily be removed by the cock arrangement found there for that purpose. In this way you should never be troubled with coke forming, and your still should always remain clean. The depth of oil, through which the distilling heat has to pass, is always a constant factor, and the nature of the oil under the action of this heat is pretty nearly uniform. The bottom of the main body of the still or distilling chamber, as I call it, is inclined downwards and inwards, and this facilitates the withdrawal of the residual matter from this chamber, as it is formed, to the cooler region at the tail-end of the still. You thus avoid all forcing of fires; no part of your still gets unduly heated; your gases have a shorter travel; and you work practically with a uniformly steady heat, the energy of which is employed in doing useful work.

I am strongly convinced, from the experiments I have already made, that such a form of still as I have placed before you this evening, whether worked in conjunction with a vacuum pump or not, would produce from a given oil a larger percentage of heavier oils, of greater viscosity, and also of high melting-point paraffin, than any other still at present in use.

REFERENCES TO PLATES.

PLATE No. 1.—Figures 1 and 2 are respectively a transverse vertical section and a longitudinal vertical section of the apparatus. The same reference letters mark the same parts when repeated, two or more similar parts are distinguished by numerals combined with letters. A, boiler still; B1 to B4, compartments in still open at bottom; C, vertical

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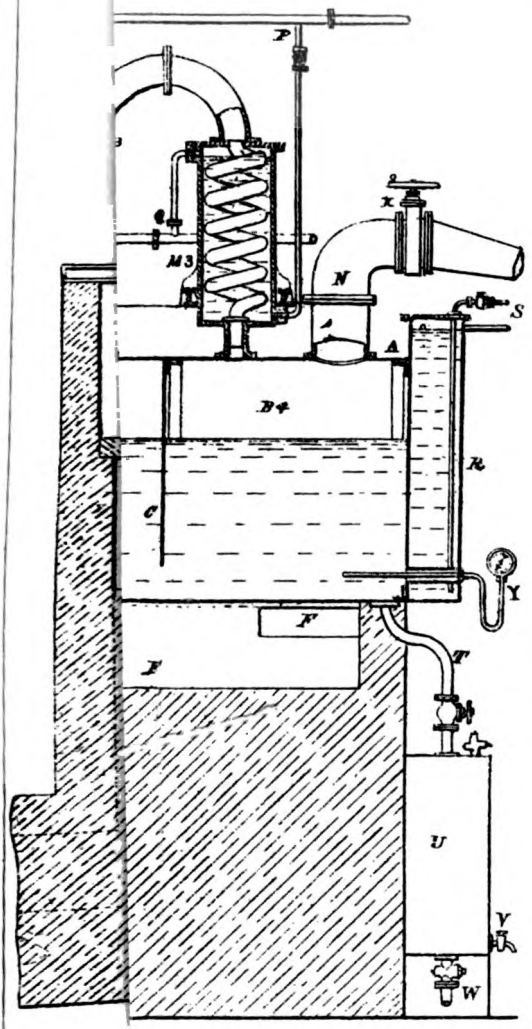

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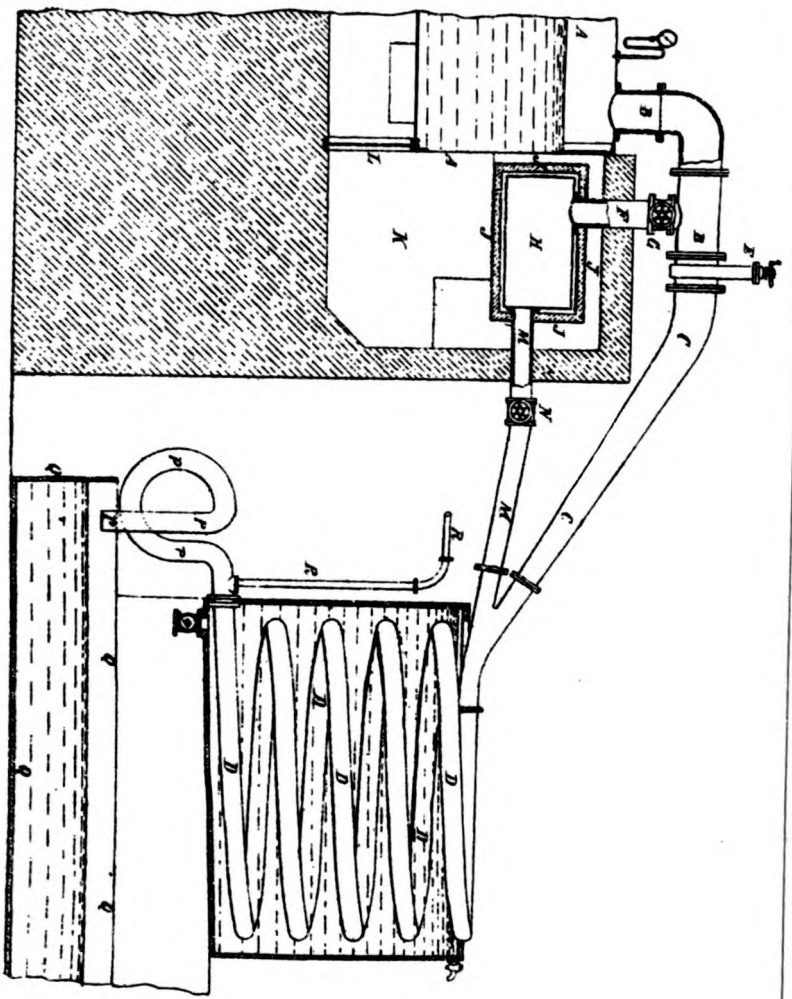
LAING ON THE DESTRUCTIVE & CONSERVATIVE DISTILLATION OF MINERAL OILS.



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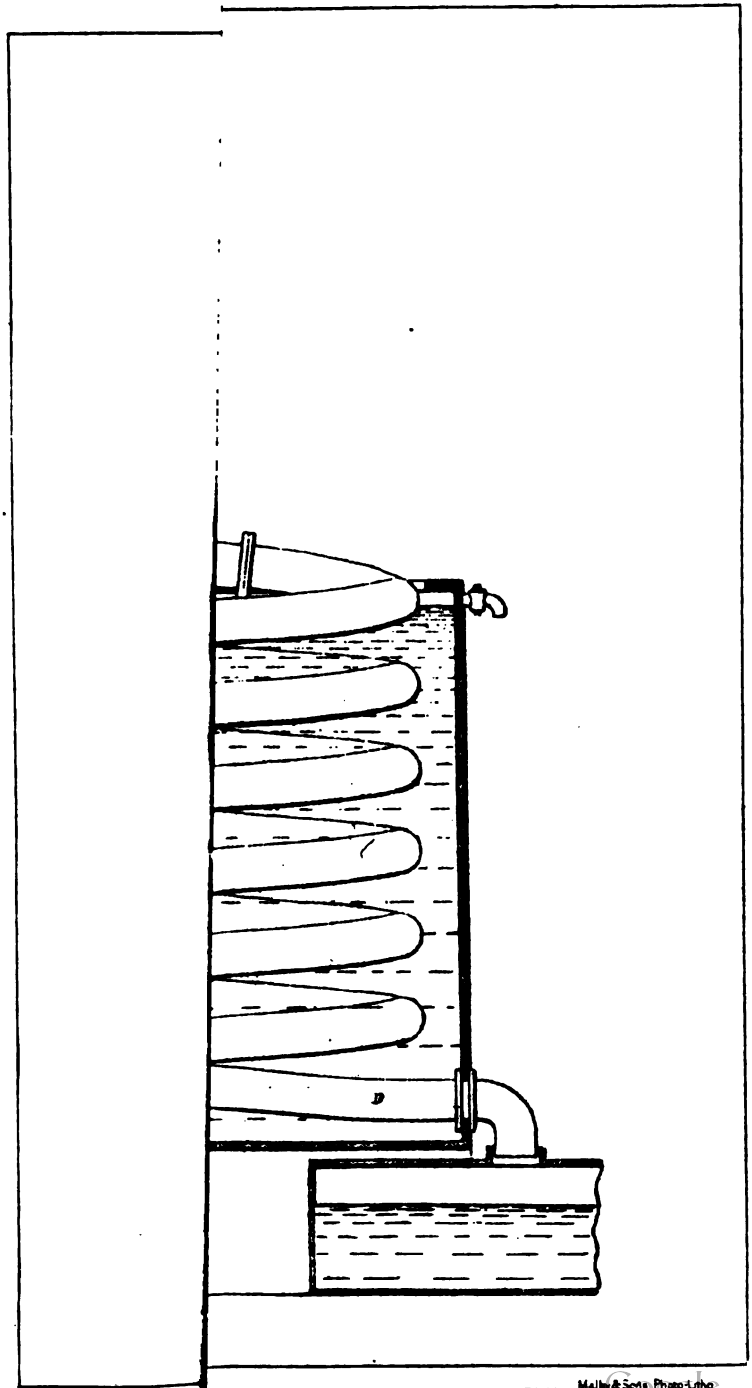

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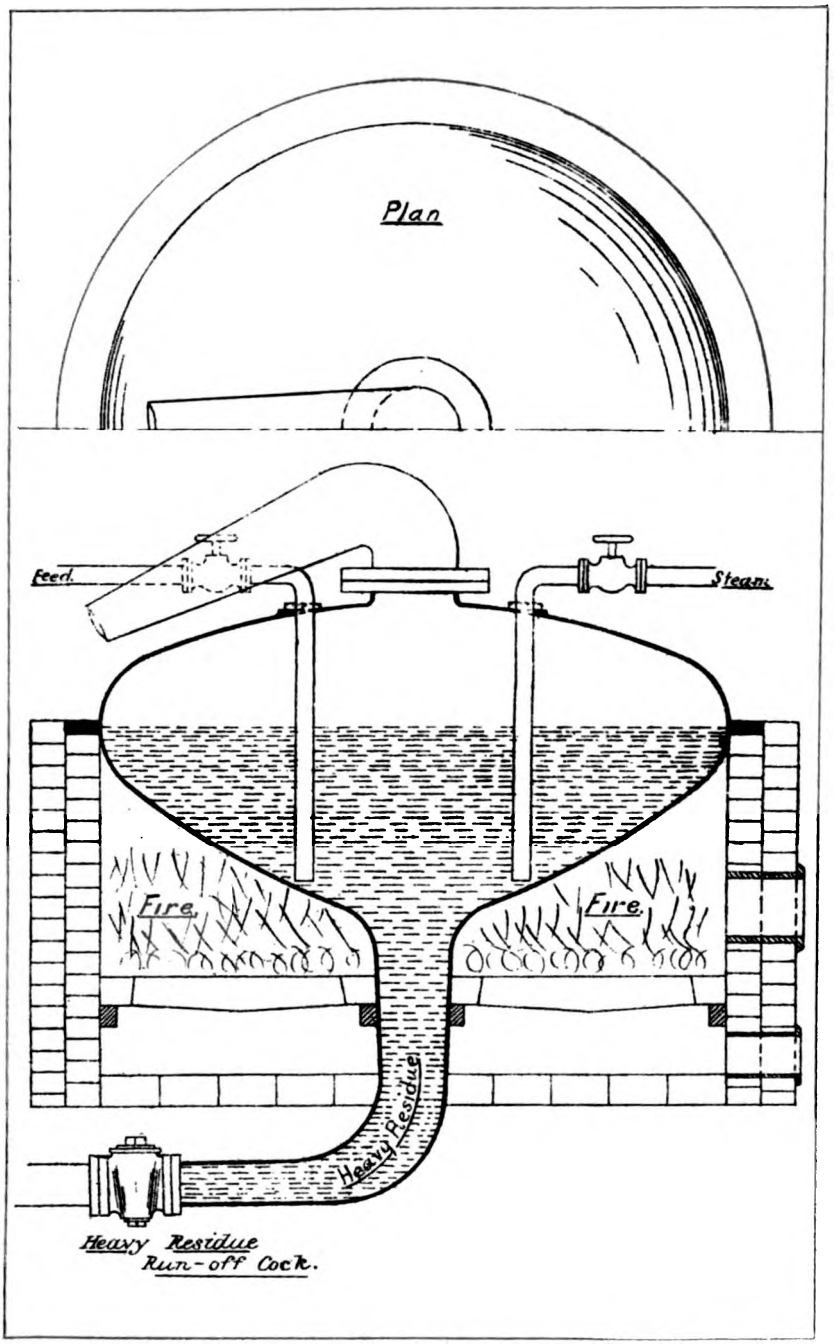

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partitions; D, furnace; E, flue; F, side ports; G, return flues at the sides of the boiler; H, horizontal flue communicating with return flues G at their front ends; J, additional ports communicating between E and G fitted with dampers; K, feed pipe; L1 to L3, gas inlets to condensers; M1 to M3, condensers; N, swan neck going to general condenser; P, cold water supply pipes going to condensers; Q, hot water outlets from condensers; R, water jacket attached to end compartment of still; S, cold water supply to water jacket with hot water outlet; T, pitch pipe from still to sampling vessel; U, pitch sampling vessel; V, sampling cock; W, run-off pitch cock; X, stricture valve on swan neck regulating outflow of gases; Y, pyrometer.

PLATE No. 2.—Radiant Heat.—Shows a longitudinal vertical section and a part of primary still. A, part of primary still; B, swan neck outlet; C, continuation of swan neck going to condensing worm; D, condensing worm in cold water tank; E, stop valve; F, branch pipe from swan neck to super-heater; G, stop valve; H, super-heater, which may be filled with scrap-iron; J, firebrick casing to moderate and equalise heat on super-heater; K, extension of boiler flue space; L, damper to regulate heat on super-heater; M, connection between super-heater and condenser; N, stop valve; P, outlet from condenser in form of siphon, and which may be extended downwards into the oil sufficiently to hold a column corresponding to the degree of vacuum required; Q, general receiving tank; R, outlet for air or incondensible gas, also a connection for vacuum pump if required.

PLATE No. 3.—Distilling under Pressure.—Shows a longitudinal vertical section and part of primary still. A, part of primary still; B, swan neck outlet; C, continuation of swan neck leading to condensing worm; D, condensing worm in cold water tank; E, stop valve; S, pressure valve; T, weighted lever of pressure valve; U, branch pipe from pressure valve to relief tank; V, relief tank in outer vessel of cold water and acting as condenser; W, cold water vessel holding relief tank; X, outlet for gases from V going to condenser; Y, outlet for condensed oil from V going through condenser to receiver; Z, inverted siphon leading off any oil condensed behind E to receiver.

On a Time Indicator. By WILLIAM STURROCK.*

Some time ago I had the privilege of bringing before the Society a system of electro-magnetic indicators propelled by the usual battery.

Those who have had experience of primary batteries know how unreliable and troublesome they are, requiring as they do constant attention.

The system which I now wish to submit to you is the

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* Read before the Society, 11th January 1892.

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result of an attempt to do without a battery by substituting magneto-electric energy.

An armature of the usual H pattern, propelled by a weight through a train of wheels, revolves on the field of a compound permanent magnet. By means of an escapement the armature makes a half revolution each minute, thus inducing a current in alternate directions. This escapement, for which I am indebted to a friend,—Mr Blenheim, an electrician,—is arranged thus: A cross-piece fixed rigidly to the axle of the armature takes the place of a 'scape-wheel; the ends of it are cut away on opposite sides, forming as it were two teeth; mounted on a long lever arm is a bolt free to move horizontally; against the point of this bolt one or other of the said teeth of the cross-piece butts; the lever is pivoted at a point behind the bolt; and at the free end of lever two steel friction rollers are mounted; on the lever being moved to either side, one of the teeth of cross-piece is freed from the point of bolt, and the armature makes a half revolution, the other tooth being arrested by the bolt which has moved aside into direct line with it, and so on *vice versa*. One great advantage is that the circuit is never broken, and consequently no contacts to get oxidised.

The reciprocating motion of lever is attained by means of a wheel driven by the third wheel in the standard clock. This wheel revolves between the friction rollers, and has on either side a series of cams arranged—a cam on one side being opposite a space in the other.

These cams in revolving act on the rollers alternately, and push the lever from side to side, so freeing the escape at the dynamo.

The current thus induced each minute in alternate directions is conducted to a series of indicators. In each indicator is a polarised relay, to the armature of which a rod is fixed, having at the end a small triangular piece of steel, which oscillates between the teeth of two wheels. These wheels are both fixed the requisite distance apart, on the arbor carrying the minute hand. Each wheel has 30 teeth, and are in the position of having the teeth of one opposite the spaces in the other. When the current causes the

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armature, with its rod and triangular piece, to oscillate, one tooth, and one only, is propelled each minute.

A considerable weight is required as motive power to the dynamo, yet in practice the standard clock is not disturbed in its timekeeping, and releases the escapement with ease. In arresting the revolution of armature at each half-turn a considerable amount of force is exerted on the point of the rod already alluded to. The free end of rod rests on a rubber ball as a cushion to take up the momentum by compression. I have utilised this compression, and by means of a tube from the ball and another form of escapement, another indicator is propelled, thus taking all advantage of energy evolved. I may state that I have had the system in operation in my own house for nearly a year, and I am satisfied that it is an improvement on the battery method.

On the Prevention of the Waste of Water with the assistance of Deacon Meters and other Appliances. By ALEXANDER LESLIE, M.I.C.E., F.R.S.E., F.G.S., President of the Society.*

So much has of late years been both written and spoken upon this subject that I feel it is difficult to add much to what has already been said of an original character. I, however, think that although many people may have read with interest the different statements and advertisements which have from time to time appeared upon this subject, it is quite possible that they may not have a thorough understanding of it. I have, therefore, agreed to submit the following paper to this meeting of the Society, and I have to express the hope that in my wording of it, I may not be accused of unnecessary plagiarism.

It is a well-acknowledged fact that the cheaper a commodity appears to be the more improbable it is that special endeavours will be made to economise its use, or in other words, to prevent its being wasted, and this applies in a special manner to water as supplied to towns by gravitation, as is the case in this city and the surrounding districts. I

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say this advisedly, as there is a great difference between the case of a gravitation water supply and one which is obtained by pumping. So long as the supply in the case of gravitation equals the demand for the time being, it is in a measure immaterial, so far as cost is concerned, whether the quantity consumed is greater or less than is actually required for the proper service of the community. It is a very different matter, however, when the water is obtained by pumping, either from a deep well or even from a shallow river, both of which are to be found in the case of the London Water Works, as every drop of water sent through the mains costs a certain sum of money, whether used or wasted, so it becomes a very important thing to see that no more coal is consumed in the operation of raising this water than is absolutely necessary.

It is not within the scope of this paper to discuss the question of how many gallons per head per day of the population may be a sufficient supply. It is an actual fact that this is found to vary very considerably in different districts, and this depends entirely on the nature and habits of the users. What we have to consider is the best means of insuring that all the water which passes through the mains and into the houses of consumers is legitimately employed, and is not permitted to run down the drains without having performed some useful work.

The method originally adopted for preventing waste of water consisted in the employment of a staff of inspectors, whose duty it was to make periodical visits to all the different houses during the day, and by examination of the various apparatus to find out whether its condition was in their opinion satisfactory, or whether it was in a state likely or certain to permit of waste going on. The result of these inspectors' day's work was handed in at the head office, and intimation was at once sent to the parties whose apparatus was found to be wasting water, and after the expiry of a sufficient time to allow the proprietors to get the different articles repaired, a subsequent inspection was made to ascertain if the proper steps in this direction had been taken. Although the adoption of this system of inspection by day is certainly very much better than none at all, it happens that for various

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reasons it cannot by any means be considered perfect. In cases where the water happens to be supplied intermittently, as until lately was the case in many parts of the country, it is not possible, while the water happens to be off, by an examination of the different pipes or ball-cocks to tell whether they will not be leaking when the pressure is on to its full extent. It is actually the case, even in places like our own, where the water is not supplied intermittently, that is to say, that the valves are not deliberately manipulated so as to afford a supply to one district and cut off entirely the supply from the district adjacent, that there is found to be such a difference in the pressure on the apparatus, during the day and during the night, that many ball-cocks and nose-cocks supplied off the main which were supposed on this inspection to be perfectly tight during the day are found to run continuously when the increased pressure takes place during the night. It therefore became obvious that some other arrangement must be come to with the view of observing the conduct of the apparatus during the night as well as during the day.

The Water Works Clauses Act provides that water inspectors may enter houses for the purpose of examining the fittings only between the hours of nine o'clock in the morning and four o'clock in the afternoon, and a recent application to Parliament for an extension of this time was met with refusal. In order to overcome this difficulty, the plan was adopted of having inspections during the night, not, of course, of the internal apparatus itself, as that was impossible, but it was effected by sounding the pipes before they enter the houses. It is well known that when any water, however little, happens to be passing through the stop-cock on one of the service mains, it causes a certain amount of noise, and this fact is utilised in the night inspection. The sound is much more distinctly observed by making use of an instrument on the principle of the ordinary medical stethoscope, by which name it also goes. By holding the ear to the end of the ordinary sluice valve-key, the slightest sound is heard, and this is intensified by the addition of a wooden stethoscope, which is usually fitted on to the cross handle of the key.

The operations are as follows:—A staff of men are employed

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during the day in searching for the position of the surface-boxes which cover the stop-cocks on the lead service-pipes of the different houses. The lids of these are all carefully loosened, and all the dirt cleared away from round about the stop-cock, and their positions are indicated on some wall adjacent. The night inspection, which is undertaken usually by those same men, whose experience enables them to find the different cocks with facility, begins about twelve o'clock at night, and is continued during the silent hours until such time as the noise of the street traffic prevents the sounds being correctly heard, and also when the legitimate use of water may be expected to commence, when, of course, the sound will be heard on every stop-cock.

It is assumed that in a place like Edinburgh, where there is constant service throughout the district of supply, and where, therefore, all the cisterns will be standing full at twelve o'clock at night, any water which is entering the house must be running to waste, as the inhabitants cannot be expected to be using the water at that hour. If, therefore, a sound is heard upon any pipe, a note is taken of it, and one of the day inspectors visits the premises on the following day. It may happen possibly that, as mentioned before, there is no water found running to waste over the waste pipes of the cisterns at the time of the day-inspector's visit, but a careful examination of the water-line of the cistern will show that the water was shortly before above the level of the overflow-pipe, although with the reduced pressure at the time of the day-inspector's visit, the ball-cock seemed to be perfectly capable of maintaining the water at the proper distance below the overflow, and therefore this was the cause of the sound which was heard on the previous night.

Of course there are other causes of waste, such as leaks in the service-pipes themselves, which no amount of inspection during the day can ever detect. If it be satisfactorily proved that the ball-cocks in the houses in question were not really to blame, then an endeavour is made to discover if the leak is on the service-pipe itself.

It will easily be seen that a leak may go on for long without anyone having a notion of its existence, as the water may be

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running direct into some drain, or be soaking into the earth under the pavement of the street, or under the flooring of the houses.

The application of this system of night inspection has been known to effect great saving in many towns—notably Norwich and Sheffield—where, under Mr Hawksley's directions, the consumption was reduced to about one-third of what it was previously.

It was with the view of facilitating the process of checking waste by night inspection that Mr Deacon, the Water Works Engineer of Liverpool, adopted what is known as the Deacon Waste Water Meter.

Of course it must be understood that no kind of regulating apparatus can in any way tend by itself to the reduction of waste. On one occasion, when advising a community in the north of Scotland on the question of their water supply, I inquired if they had ever had the subject of the application of the Deacon meters before them. I was asked to say no more on that subject, as they had gone to the expense of purchasing two of them, which had been in use for upwards of two years, and the consumption had just remained the same as before. It is therefore necessary to bear in mind that the use of the Deacon meter is not to prevent waste, but merely to indicate its existence, and also the position of the leakages which it discovers.

The meter proper consists of nothing more than a vertical truncated hollow cone, having its small end downwards, and containing within it a disc of the same diameter as the small end of the truncated cone. A central stalk on the upper surface of this disc is suspended from a fine German silver wire, which passes, practically water-tight, through a small hole in the upper part of the chamber above the cone, and is attached to a guided cross-head, carrying a pencil or tracer, and having above it a band passing over a pulley, and supporting on the other side of the pulley a weight, which is a determinate amount lighter than the cross-head and disc, when the disc is weighed in water, so that the disc always tends towards the bottom of the truncated cone. The inlet for water is in the chamber below the cone; the outlet proceeds from a chamber above it.

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In the upper chamber there is a diaphragm, with openings to equalise the flow of the water.

Assume that water is supplied to the meter, but that none is passing through it, because all the outlets are closed, then the disc will have fallen to the extreme point of its travel, and so as to fill up the aperture at the bottom of the cone. If now a cock in the outlet be opened, say to a small extent, water will seek to flow; but in endeavouring to do so, it must press upon the disc, and send it upwards to a larger part of the cone, and the point where the ascent of the disc will cease will be that at which the annular area between the edge of the disc and the interior of the cone is sufficient, under the difference of pressure between the under and the upper side of the disc, to enable the required quantity of water to pass. The tracer rises and falls with the disc, and if this tracer have a piece of paper presented to it it will draw a vertical line on that paper, the length of which will indicate the rate at which the water is passing through the meter; and if this paper be printed with horizontal lines representing hundreds and thousands of gallons per hour, then an inspection would show at which of these lines the tracer was standing, and would enable an observer at once to say:—"Water is now passing through the meter at a velocity equal to 1000 gallons, or 3000 gallons per hour," as the case may be.

As the instrument is furnished with a clock, which drives a drum round once in twenty-four hours, it is easily seen that the amount of discharge at any minute of the day, or night, can be accurately ascertained.

Another form of meter has been invented by Mr Ginman, and there does not seem to be any reason why it should not work as well as the Deacon meter, and his statement to me goes to show that they are equally efficient. It is on the same principle, but with a little difference in the details of its construction. Its action is that of a reflux, or flap-valve, which remains shut when no water is passing, and moves forward when the current commences. The movement of the flap is communicated by the hinge through a stuffing-box to the end of a lever, by which is worked the marking pencil which registers the movements on a

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revolving drum, in precisely the same way as in the Deacon meter.

Another apparatus was put in use for some time, being an adaptation of Guest and Chrimes "Siemen's" meter, but the results to be got by using it are not nearly so satisfactory. It certainly indicates the amount of consumption in the pipe on which it is placed, say during any number of hours or minutes, very well, but some difficulty is experienced in analysing the results of the pencil lines.

The manner of conducting night inspections by means of the Deacon, or other similar meter, is as follows:—

The town is divided off into suitable districts, containing each a population of from 2000 to 3000, as can be most conveniently arranged. In laying out the distribution pipes of any town for the first time, it would be a simple enough matter to have this attended to at the first, but in a place where the pipes have been laid and relaid, and duplicated for nearly seventy years, it becomes a matter of great difficulty, and also of expense, to get these districts laid off so as to be efficient.

A district may be supposed to contain eight blocks of houses, and a main-pipe, say 4 inches in diameter, on which a meter is placed, and it must also be understood that there is no connection with any other pipe, so that all the water passing through the meter must be consumed in the district under observation.

The first operation consists in fixing a diagram on to the drum of the meter, and allowing it to work without interfering with the houses, till an accurate idea is obtained of the amount of daily consumption through this pipe. The next operation consists—say the following night, or later on, if necessary—in going round all the stop-cocks on the branches off the main, and shutting off each street at intervals of any fixed time—say a quarter of an hour—until the whole of the pipes are entirely shut off the main. The meter is allowed to go on for some time after this, and the diagram is removed and inspected the following morning.

Suppose there is a flow amounting to 3000 gallons per hour being registered by the pencil of the diagram at pre-

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cisely half-past twelve o'clock, at which time the first street may be supposed to be cut off, and the diagram continues to register by a horizontal line in the same position, it is easily seen that there is no consumption of water in the street which has first been shut off. We will suppose now that in shutting off No. 2 street at one o'clock there is a drop on the pencil amounting to an equivalent of 500 gallons per hour. It is obvious that some fault is to be looked for in that street. We may assume that the third street on being dealt with causes no alteration on the horizontal line, therefore it may be assumed to be also free from fault; and so on to the end of the district. It is therefore only necessary that observations should be made upon individual houses in the streets which have been found to be passing the water. The following night, with a new paper on the drum, another diagram is taken by shutting the stop-cocks of each house service-pipe, and thus observing the effect on the diagram. It may happen that only half the houses are wasting water, therefore only half the number in this street require to be examined by the day-inspectors.

Conclusion.

I have now given a brief account of the manner in which waste is sought for and prevented, as carried out by nearly all water companies and commissioners throughout the country. You never find gas companies or commissioners making similar rounds of inspection to see if the gas-pipes are in proper order. The smell, which fortunately always accompanies waste of gas, is of itself a sufficient guarantee that waste will be at once put a stop to, not to speak of the danger entailed by any carelessness in connection with gas service; and if water was provided at the same price as gas, namely, fifty-six times the trade price of water, then I feel sure that waste prevention would be gone about *con amore* by the proper parties—not the trustees, but by the consumers themselves—and in that case there would not require to be so much talk about proper supervision, and the days of Deacon meters and their attendant expense would be numbered.

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On the Application of Wind Power to the Production of Electric Currents. By Professor JAMES BLYTH, M.A., F.R.S.E.*

At the present time the employment of the form of energy known as the electric current to industrial purposes has become very extensive, and in the near future its application in that direction is likely to be still further increased. We have already many large private installations of electric light. Every steamboat of any size is now electrically lit. In many places the current is used for the transmission of power. Already several large towns have adopted it instead of gas for street lighting, and the question of general house to house lighting is one whose solution only awaits a slightly greater economy in current production and distribution. It may be said that, as yet, the current is generated almost exclusively by dynamos driven by steam-engines, so that it is merely a transformation of the potential energy of coal, and, so long as this is the case, it is obvious that any cheapening in its production can only arise either from an increase in the efficiency of the dynamo, or of the steam engines, or of both. Now these machines have attained so great an efficiency that there is scarcely any hope for much improvement in this direction. Primary batteries of several forms have been suggested and tried, but currents got from the oxidation of metals will always, I think, be too dear for practical purposes. Something may be expected from thermo-electric batteries, for here we have the direct transformation of heat into current electricity without the intervention of the wasteful middleman represented by the steam-engine and dynamo. This, however, can hardly be said to have reached even the experimental stage. Considerations such as these have led electrical engineers to look about and see if there may not be some other source of power at present unused which might be utilised for current production. Naturally, water power first suggests itself. The Niagara falls have often been spoken about and their available energy for that

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purpose calculated. In several places electric lights are run from water-wheels where the fall happens to be near at hand, but in the great majority of cases the available falls of any size are so far from the centres of population that the cost of conducting the current almost prohibits its use. Much, no doubt, may be done by employing rapid alternating currents of high voltage, and so diminishing the cross section of the necessary leads, but even then, when the distance is considerable, the cost of conduction comes in as a serious item. And, besides, water power is not free. Although a fall may be unused just now, still when it is proposed to use it, it immediately acquires a money value, and must either be rented or bought outright. Next, after water power, comes the consideration of wind power, and it is about this that I am principally to speak. The wind is proverbially free, and is to be had everywhere, although it is of a very intermittent nature. Up till recently this entirely precluded its use for current generation, as it was obviously impossible for it to work electric lights or do any kind of work where a steady current at a fixed time was required. But all this has been changed by the invention of storage cells or accumulators. These are now highly efficient, though a little too expensive; but disregarding the expense, we are now able to store any quantity of electric energy and get a high return, even although a considerable time elapses between the storing and the using of it. No sooner were the accumulators invented than windmills for electric storage began to be thought of. At the York meeting of the British Association, Lord Kelvin suggested the construction of cheap windmills to run dynamos for charging accumulators, but so far as I know no practical trial was made till the summer of 1887, when I erected my first electric windmill in the village of Marykirk, Kincardineshire. At that time I procured a set of thirteen accumulators, and constructed a windmill of the old English type, having four arms or whips and canvas sails; the length of the arms was about fourteen feet, and the sails were 8 feet by 3 feet. The mill was provided with bevelled gearing at the top of a vertical shaft, and bevelled gearing below, so arranged that the driving wheel always moved in the same vertical plane, no matter in what direction the wind shaft pointed. The

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mill was turned into the wind by hand, having no tail or other gearing for keeping it automatically head to wind. The dynamo was driven by a belt from the driving wheel, and with this I was able in two or three windy days to store a few cells. Although the experiment was not on a very large scale it was sufficient to show that accumulators could quite well be charged, when the electrical connections were properly made, by a dynamo driven at the irregular speed characteristic of a windmill. Sails I found were no great success, especially since I had no means of reefing them. To prevent them being torn to pieces, the mill had to be stopped when the wind was too high, that is, just at the time when it should have been going at its best. To remedy this partially I altered (the next summer) the wind-wheel from the English to the American type, having a number of arms and blades of cast iron. I also introduced the further improvement of doing away with the driving wheel being always made to go in the same plane. This is absolutely necessary if the windmill is to drive a sawmill, a cornmill, or anything of that sort; but for electrical purposes the dynamo can quite easily be attached to the wind-shaft platform so as to turn with the mill as the wind changes. In this way all gearing is avoided, as the dynamo can be driven by ropes from a large wheel keyed directly on to the wind shaft. This form of mill I found to answer very well so long as the wind had a moderate speed, but like all other wind millers, I soon found that the mill had either to be made self-reefing or stopped altogether when a breeze came. This is obviously very unsatisfactory, as the best of the wind for storage purposes is lost, and hence this problem presented itself, viz., how to construct a windmill that would satisfy the following requisites:—1. It must be always ready to go. 2. It must go without attendance for lengthened periods. 3. It must go through the wildest gale and be able to take full advantage of it. A possible solution of the problem is presented in the Robinson Anemometer, which consists of four hemispherical cups attached to four arms and moving in a horizontal plane about a vertical axis. From the theory of this instrument, which is, however, only approximate, it appeared that whatever the speed of the wind

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might be, the speed of the cups attained a certain terminal value, such that the couple due to the wind pressure was exactly equal to that produced by the motion through the air and the friction of the bearings. It immediately followed that a large machine made on this principle would have the same property, and hence could be allowed to run without damage, even when in the strongest breeze and when doing no work. Last summer I erected a machine of this kind. The cups are replaced by semi-cylindrical boxes attached to four strong arms, each about 26 feet long; the opening of each box is 10 feet by 6 feet, and the vertical shaft is a long rod of iron 5 inches in diameter. At the lower end it carries a massive pit wheel which actuates a train of gearing and drives a fly wheel 6 feet in diameter with the requisite speed for driving a dynamo connected with it by a belt in the ordinary way. This machine worked most satisfactorily, and with a fair wind speed gave about 4 electrical horse power. I also tested it in a strong gale by allowing it to run with no load, and the result was perfectly satisfactory, as a terminal speed was attained and all racing avoided. Hence, I think that electrical windmills are likely to assume this form, as there is no limit to the size and strength with which they may be constructed, and if necessary several could be placed in any well-exposed position, each having its own dynamo and set of accumulators. Regarding the electrical connections I may say a word. All that is needed is that the circuit be broken when the dynamo is running at a less than the storage speed. This is easily managed by a governor attached to the dynamo shaft, and which makes and breaks contact in a mercury pool at the required speeds. I have also tried a form of governor which throws a greater or less number of cells into the charging circuit as the wind varies, and in this way the machine is always doing some work. We may next turn to the uses for which windmills are specially applicable; these are:—

1*st*. For lighting lighthouses. These are always on exposed situations, where wind is plentiful, and often in such out-of-the-way places, that stores and coal for generating the electric light in any other way could only be sent with difficulty. At present a large windmill is

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doing the work of lighting the two lighthouses on Cap de la Hero, near Havre, and, as far as I have heard, with satisfactory results.

2*nd*. For the lighting of private country mansions. Here, whatever form of power is used, accumulators must be provided. The wind, I think, specially recommends itself from its cleanly nature, if it can be applied without the trouble of much attendance.

3*rd*. For factories so situated that a suitable mill could be placed on the roof, and thus be in an exposed situation.

In closing, I may just refer to the probability that the present system of electric lighting by incandescence will be superseded by some method of getting light from cold sources. When we think that 99 per cent. of the energy spent in a gas flame is wasted as far as light is concerned, that a percentage almost as high in the electric light is also wasted, we are strongly tempted to think that lighting by incandescence cannot be a final form. Recent discovery has distinctly proved that rapidly oscillating currents send out waves exactly similar to light waves, but only having a much greater wave length. Attempts have been made to get alternate current machines of such frequency as to send out such waves. Should these be successful, then light will be generated with much less expenditure of energy, and windmills, even of very moderate power, may be all that is required. I can quite easily fancy the time coming when each house has its own little windmill storing currents, which may be used to drive such machines as those alluded to, and giving a light from a comparatively cold source suitable for the house. We should not require to drive large steam-engines in order merely to let us see each other, or read a newspaper.

APPENDIX.

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APPENDIX.

Theory of the Vertical Windmill.

When the wind impinges normally upon a surface the pressure at a point is found to vary as the square of the relative velocity. Hence, if V be the velocity of the wind, and P the pressure, and a a constant, the normal pressure on the surface at rest will be :—

$$P = aV^2 \qquad (1)$$

When, however, the surface is oblique to the direction of the wind, the normal pressure will vary from this value to zero, as the angle between the normal to the surface and the direction of V increases from 0° to 90°. Hence this normal pressure N will be equal to P multiplied by some function of θ, so that :—

$$N = Pf(\theta) \qquad (2)$$

Various experiments have ascertained the value of $f(\theta)$.

Hutton gives the rule $f(\theta) = \sec\theta(\cos\theta)^{1\cdot 288(\cos\theta)}$, while Duchemin gives the more convenient expression :—

$$f(\theta) = \frac{2\cos\theta}{1+\cos^2\theta}.$$

If we adopt the latter, we have, when the vane is at rest :—

$$N = aV^2 \cdot \frac{2\cos\theta}{1+\cos^2\theta} = \frac{2aV^2}{\sec\theta+\cos\theta}.$$

Breaking this up into two components, S in the direction of the wind producing pressure on the wind shaft only, and R perpendicular to that direction tending to produce motion about it, we have :—

$$R = N\sin\theta = \frac{2aV^2\sin\theta}{\sec\theta+\cos\theta}.$$

When the sail is in motion with speed v in the direction of R, the relative velocity of wind and sail is $\sqrt{V^2+v^2}$, and the direction of this velocity makes with that of V an angle ϕ, such that $\tan\phi = \frac{v}{V}$: so that to get the value of R for the

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moving sail we must replace V by $\sqrt{V^2+v^2}$, and θ by the angle $\theta+\phi$. This gives

$$R=\frac{2a(V^2+v^2)\sin\theta}{\sec(\theta+\phi)+\cos(\theta+\phi)}.$$

If R be the radius to the point considered, and ω the angular velocity, we have finally for the activity A per square foot of surface, or work done in foot pounds per second per square foot of sail, the expression

$$A=Rr\omega=\frac{2ar\omega(V^2+v^2)\sin\theta}{\sec(\theta+\phi)+\cos(\theta+\phi)}.$$

This will be a maximum for a given value of ϕ when the fraction $\frac{\sin\theta}{\sin(\theta+\phi)+\cos(\theta+\phi)}$ is a maximum, and from this, by the ordinary method, we find $\theta=67\frac{1}{2}^\circ-\frac{3}{4}\phi$.

From this can be calculated the best angle of weather which is equal to θ, for each point of the sail. It will vary from $67\frac{1}{2}^\circ$ at the wind shaft, where v is zero, to the value determined by the ratio of ϕ at the top of the sail. To find the total activity, divide the sail into strips, and integrate over its length and breadth, taking into account V, v, and θ.

This calculated value depends upon the constant a, which can only be determined by experiment, a is very uncertain, as it depends upon the unknown resistance called into play by the mere churning of the air as the sail moves through it. For practical purposes, a has the value ·001. In most cases the power of a windmill is best got from the brake. For my purpose I found it sufficient to take the electrical horse-power as determined by the product of the current, and the voltage at the terminals of the dynamo.

Theory of the Box Horizontal Windmill.

To find the best form of section for the boxes, I fell back upon an analogous problem first solved by Bernoulli, under which he deals with the form of a rectangular sail attached to horizontal yards, and which are perpendicular to the wind.

Let ACB be a vertical section of the sail, A and B being

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the yards. Let ds be an element of the section at P, V the velocity of wind which is horizontal, and θ the angle between the normal PN and the direction of V.

Case I.—If the wind escapes after it strikes P, then the pressure at P is proportional to the square of the normal component of the wind's velocity, denote it by R; then $R = aV^2\cos^2\theta$, but if T be the tension at P which is constant, and ρ the radius of curvature at P, we have $\frac{T}{\rho} ds = R ds$; therefore

$$\frac{T}{\rho} = av^2\cos^2\theta,$$

putting $\frac{T}{a v^2} = C$ (a constant), we have $\frac{C}{\rho} = \cos^2\theta$, which indicates a catenary with axis horizontal and direction vertical.

Case II.—If the wind does not escape after striking, but is confined, as in the case of the boxes, the air exerts a hydrostatic pressure which is equal in all directions. Hence the difference between the pressure on the concave side and on the convex side is constant. Let the difference be R, then we have :—

$$\frac{T}{\rho} ds = R ds; \text{ therefore } \frac{1}{\rho} = \frac{R}{T} = a \text{ constant},$$

and hence the curve is a circle.

Let fig. (3) represent a horizontal section of the masting through the arm. P is the centre of a box. PR is the direction of the wind, whose speed is V, and PS the direction of the box, whose speed is v. Also let θ be the angle SPR. Then if v' = the relative velocity of the wind and the point P, $v'^2 = V^2 - 2Vv\cos\theta + v^2$.

Now the pressure of the wind is proportional to v'^2, and the resistance due to the air is also proportional to v'^2. Therefore the mean torque due to wind pressure and air resistance may be assumed to be a quadratic function of V and v. Denote it by L, then $L = \pm AV^2 \pm BVv \pm Cv^2$, when A and B and C are constants with as yet undetermined signs. The signs may be got as follows :—(1) Since the mean moment must be positive at starting, L is positive when $v = o$, hence A is +. (2) When the mill begins to move, the wind pres-

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sure decreases, and hence $\frac{dL}{dv}$ must be minus when v is small. Now $\frac{dL}{dv} = \pm BV \pm 2Cv$; from this B is minus. (3) When the wind stops, the resistance will stop the mill. Here L is $-$ when $V = o$, therefore C is minus. Hence we have $L = AV^2 - BVv - Cv^2$. Now, if the machine has no load, v will increase till the torque due to the resistance just balances that due to the wind pressure.

When that is the case, $L = o$, and we have a quadratic for finding the ratio $\frac{v}{V}$ in lieu of A, B, and C. That is to say, we assume a terminal value for each speed of wind. In the Robinson anemometer this is about $\frac{1}{3}$.

On the Diazotype Process of Photographic Dyeing and Printing. By E. J. BEVAN, Consulting Chemist, London, Analyst to County of Middlesex.*

The subject of this lecture is a new application of a group of colouring matters discovered by Green more than five years ago. This group, of which the dyestuff known as "primuline" is the typical representative, is characterised by the special property of dyeing cotton and other textile fabrics from an alkaline or neutral bath in such a way that the colouring matters may be diazotised upon the fibre without in any way affecting the union with the fibre substance; and the diazo derivative may then be combined, also *in situ*, with various phenols and amines, to produce colouring matters exhibiting a wide range of tone and shade. These colouring matters being thus synthesised within the fibre are distinguished by considerable resistance to alkaline detergents, and when thus produced are known as "Ingrain Colours."

Primuline itself is the sodium sulphonate of a complex amido base, which is obtained by heating para-toluidine with sulphur. Its formation is preceded by that of dehydrothioto-

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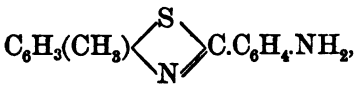
luidine, a body which appears to be an amidobenzenyl-amidothiocresol—



and primuline-base appears to result from a further condensation of this compound, and to differ from it in the same way that dehydrothiotoluidine itself differs from para-toluidine.

The following formula for primuline proposed by Gatterman will give some idea of its constitution:—

Homologues of primuline closely similar to it in properties are similarly obtained from meta-xylidine and pseudocumidine.

The special photographic application of this group of colouring matters, which I am about to describe, depends in the first instance upon the sensitiveness to light of their diazo derivatives, this sensitiveness being increased in a very remarkable degree by combination with the complex colloids which constitute the textile fibres. Under these circumstances the diazo derivatives are completely decomposed by light, the product of decomposition being inert substances incapable of combining with amines or phenols. This fact, taken in conjunction with the special affinity of these bodies for textile fibres, gives all the conditions necessary for the production of photographic pictures; the actual photographic agent being the diazo-primuline, in which form the image is produced, and the development of the image consisting in its conversion into any of the colouring matters obtainable by combination with phenols and amines. As an illustration of the process we may take the production of coloured photographic designs upon cotton cloth.

The material is first dyed with primuline from a hot bath, to which some common salt may be added, by which it acquires a primrose yellow colour. It is then washed and diazotised by being immersed for half a minute in a cold

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solution of sodium nitrite (¼ per cent.) which has been sharply acidified with hydrochloric, sulphuric, or other acid. The material is now washed in cold water and stretched out on a level white surface, and exposed to light beneath the object of which it is required to produce a photograph. We may, of course, print from ordinary photographic positives, or from natural objects, or from any painted, printed, or photographed design or picture upon any sufficiently transparent material. Either sunlight or an artificial light of sufficient intensity may be employed, the time of exposure, of course, varying with the intensity of the light; in printing by daylight, the exposure varies from half a minute in bright sunshine to nearly half an hour in very dull weather.

When the decomposition of the diazo compound in the "high lights" of the picture is complete, which can easily be ascertained by means of a test slip exposed simultaneously, these portions will be found to have changed from an orange to a pale yellow. The material is now either passed into the developing bath at once, or is kept in the dark until it is convenient to develop the image. The developing bath consists of a weak solution (about ¼ per cent.) of a suitable phenol or amine, depending upon the colour in which it is required to produce the design. The following phenols and amines amongst others have been found to give good results:—

For Red—An alkaline solution of β-naphthol.

For Maroon—An alkaline solution of β-naphtholdisulphonic acid.

For Yellow—An alkaline solution of phenol.

For Orange—An alkaline solution of resorcin.

For Brown—A slightly alkaline solution of pyrogallol or a solution of phenylenediamine hydrochloride.

For Purple—A solution of α-naphthylamine hydrochloride.

For Blue—A slightly acid solution of eikonogen (amido-β-naphthol-β-sulphonate of sodium).

If it is required to produce the design in two or more colours, the respective developers, suitably thickened with starch if necessary, may be applied locally by means of a

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brush or pad. After development, which with cotton is complete in less than a minute, the material is washed, and the picture requires no further fixing. In the case of the purple and blue developers it is necessary to wash the material finally in a very weak solution of tartaric acid.

Velveteen, linen, silk, wool, and other fabrics are treated in the same way, except that in the case of wool and silk a longer exposure to light is necessary, and the immersion in the nitrite and developing baths must also be more prolonged. The maroon and blue developers are not suitable for silk and wool.

Architectural and engineering drawings can be copied with clearness and accuracy upon paper or calico which has been dyed with primuline, diazotised, and dried. The copy is developed by brushing over the surface a solution of β-naphthol or α-naphthylamine.

Transparent photographic pictures can be produced upon glass or celluloid by coating them with a film of gelatin containing primuline, then diazotising with nitrous acid, printing, say from a carbon or silver positive, and developing as before.

In point of simplicity the process leaves nothing to be desired; and in regard to cost, offers considerable advantages over any known process of photographic printing.

So far as I am aware, it is the first process which has been devised in which derivatives of the aromatic hydrocarbons are employed for the production of a *positive* image capable of development in colour. In this respect it differs altogether from that recently published by A. Feer. This process depends upon the sensitiveness to light of the diazo-sulphonates, produced by the action of the inorganic sulphites upon diazo compounds.

The action of the light consists in a dissociation of the diazo-sulphonate, the diazo group being set free. If, therefore, a mixture of such a compound with a phenol capable of reacting with the diazo derivative (to form a colouring matter), be exposed to light, synthetic union takes place between the diazo group and the phenol, in proportion as the former is set free; and if, therefore, the exposure takes place as in the

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ordinary process of photographic printing, a coloured image or picture results. The product of the union being a colouring matter sufficiently insoluble to resist washing, the unaltered mixture of diazo-sulphonate and phenol being, on the other hand, freely soluble, the print is finally fixed by copious washing. By this method it is obvious that a *negative* is produced, and is fully *developed* in and by the printing process, whereas, in the primuline process, the light acting as a *des*tructive, not *con*structive agent, the exactly opposite result is produced, and the development of the image is a subsequent operation.

In comparing the diazotype process with the ordinary methods of photographic printing, the next question which arises is as to the mode of action of the light, considered (*a*) physically, and (*b*) chemically.

(*a*) The rays which decompose the diazotised primuline are different in order and distribution from those which attack silver bromide. Photographs of the spectrum by the two processes taken side by side show, in the case of the diazo print, a sensible shifting of the area of maximum effect towards the red.

(*b*) In regard to the chemical changes which accompany the "discharge" of the diazo-primuline on exposure, the main point which has been established is, that the diazo group ($-N=N-$) is completely eliminated as free nitrogen. The evolution of gas is easily observed by allowing the light to act upon the sensitive surface submerged in water; and quantitative observations showed that the volume of gas evolved was in accordance with the requirements of the formula, on the hypothesis that the diazo-nitrogen was split off. This result is confirmed by the observation that the product of decomposition is not re-converted into primuline, nor into the corresponding hydrazine by treatment with sodium hyposulphite ("hydrosulphite"), or with stannous chloride. As to the constitution of the product, it remains undecided whether it is the phenol corresponding to the diazo-primuline, the decomposition being analogous to that of the diazo-benzene by heat, or whether the primuline residue enters the molecule of the cellulose or other medium which

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carries it. The latter hypothesis is supported by the fact already mentioned, that the molecular union of the diazo-primuline with the colloid medium is a necessary condition of the reaction, for the free diazo-primuline when exposed to light in a thin film is either not decomposed at all or only after very prolonged exposure.

Mr E. W. Foxlee has found that pictures can be produced by causing heated engraved blocks to act upon paper or cloth treated with diazotised primuline. Those parts in contact with the heated surface are decomposed and are therefore no longer capable of combining with any of the developers.

Explosives as used in Rock-blasting. By ALEXANDER CLARK, Kirkcaldy.*

Rock-blasting may have for its object simply the removal of the stone without regard to any use to be made of it, as in the case of a railway cutting or the excavation for a dock or harbour. If the material be very dense and hard to pierce by boring, it will be found most economical to use a powerful explosive, which will require smaller bore-holes, and will effectually shatter the rock into fragments, so that it may be more easily removed. Besides getting the maximum effect with such an explosive on the portion actually removed, the adjoining rock will be considerably affected if the explosive has been sufficiently confined.

If, again, the material to be excavated is of a soft and friable composition, such as schist, blaize, boulder clay, or such like, it will give a much better result to use a less violent explosive, which will have a lifting more than a breaking effect. In this case a large bore-hole with a heavier charge of a slow combustion powder will have much more effect than a charge of an instantaneous explosive of equal power.

Again, in excavating rocks, there may be an object in having the pieces as large as possible, or of useful sizes for

* Read before the Society, 22nd February 1892.

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special purposes. Such are most quarrying operations for monumental or building stones, or works in railway or dock cuttings, where the stone is of good quality and serviceable for constructive works. In cases such as these, great care requires to be exercised, so that the stone may not be broken by too heavy explosions; the holes bored for explosives are placed as near as possible to some natural joint, or where this cannot be got at, the weakest point in the rock, where a small shot may break up the way for a larger explosion to follow. Very often it is necessary, even where a large quantity of rock is to be removed, to put in a small charge to open out the joint, so that a larger quantity may be used again in the same hole for the complete removal of the rock. A large piece of rock may thus sometimes be shaken repeatedly before the final charge is put in. In any operations such as these, strong and violent explosives are quite inadmissible; slow combustion is absolutely necessary if the rock is to be preserved as nearly as possible without flaw. The quarryman generally finds that the rock has naturally more flaws than he would care to see.

Further, besides considering the nature of the materials to be excavated and the objects to which they are to be applied, it is necessary to consider if the rock is water-bearing, as some explosives only can be used in wet places without special provision for their protection. It may thus be necessary to use some explosives entirely under water: some are rendered inoperative by damp, some require special provision for ignition or detonation, while others act in water in exactly the same way as in a dry position.

Again, owing to the varieties in the forms of rock excavation it will be very difficult to arrive at any general rule as to the quantity of explosive material required for a given amount of rock. A large area, such as a dock excavation having abundant space on at least two sides, may require only a small weight of explosive proportionately with a narrow railway cutting, and this again will consume much less explosive material proportionately with a cutting in a small sewer trench. If the cutting be worked so that the rock slips naturally off its bed, it will also require less

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material than when it has to be lifted against the natural dip of the rock.

Chemical Composition and Energy Developed.

1. *Gunpowder.*—The composition of gunpowder, according to the old time-honoured custom, is:—

Nitre, ...	75 per cent.
Charcoal, ...	12·5 „
Sulphur, ...	12·5 „

Taking the nearest chemical formula which will represent this composition, so that we may the more readily calculate the volume of the gases produced by the perfect combustion of the compound, we have:—

$2(KNO^3)+3C+S=2N+3CO^2+SK^2=8$ volumes of gas.

Per Cent.	Grammes.	Grammes.	Gas.	Vols.	Grammes.
		78	2K		
74·8	202	28	2N →	2 vol. N	28
		96	$2O^3$ ↗	6 vol. CO_2	132
13·3	36	36	3C ↗		
11·9	32	32	S——		110
100·0	270			8 vols.	270

Supposing the combustion to be complete, these 8 volumes of gases would, at the temperature of 0° C. and ordinary atmospheric pressure (760 mm.), give $8\times11{\cdot}2$ litres $=89{\cdot}6$ litres. If the space occupied by the gunpowder be considered the same as an equal bulk of water at the same temperature (1·000 grammes per cubic litre), the 270 grammes would $={\cdot}270$. $\therefore \frac{89{\cdot}6}{{\cdot}270}$ litres = expansion of 332 volumes.

This may be taken as a sample of a high-class powder. Ordinary blasting powder often contains a much smaller proportion of nitre, of which the following may be taken as an example:—$NO^3K+3C+S=N+CO^2+CO+SK=5$ volumes. In this instance carbonic oxide is taken as a resultant of combustion, whereas carbonic acid only was shown as the product in the former. Under ordinary pressure and temperature carbonic acid is invariably formed in the first instance, but

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under the influence of a strong red heat, and particularly in the heat developed by explosion, carbonic oxide is produced, and found to be the more stable compound. Part of the carbon in this instance is not combined.

If we calculate the amount of expansion by the heat produced by the complete oxidation of 36 grammes of carbon, divided by the specific heat of the combined gases and their weight, we shall find approximately the further increase in volume due to the combustion. The complete oxidation of one gramme of carbon (charcoal) produces 8080° units of heat, or enough heat to raise 8080 grammes of water 1° C. in temperature. The specific heat of carbonic acid is ·2164, that of nitrogen ·2440, or equal to an average of ·2230 for the 6 volumes of carbonic acid and 2 of nitrogen.

We shall then have $\frac{8080° \times 36}{·223 \times 270} = 4681°$ C. to raise temperature of the gases produced by explosion.

Now, as for every 273° rise of temperature the amount of expansion is equal to the original volume $\frac{4681°}{273°} = 17·8$ times the volume of gas produced, and we have already found that in the first formula the gases produced occupied 332 times the volume of the powder. $\therefore 332 \times 17·8 = 5909$ times the original volume of the explosive.

If the whole of this gas were produced instantaneously before any disruption or yielding of the strata had taken place, the pressure produced by this charge would be about 38·8 tons on the square inch, or about 6102 kilogrammes on the square centimetre. But here the great difficulty arises to discover the actual amount of pressure at a particular instant by the evolution of gas from an explosive mixture, and this is complicated in the case of rock-blasting by the variable nature of the strata, and the joints of the rock which would undoubtedly be permeated with the gaseous compounds before such an extraordinary pressure could possibly develop.

Various experiments have been made with the view of ascertaining the exact amount of energy developed by explosive mixtures, but the limits of our space will not allow us to enter into these details.

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The speed of combustion is a most important point in the use of gunpowder for quarrying purposes, where it is important that the stone should not be broken into fragments, but opened up only at the natural beds and joints. In granite quarries, the usual custom is to bore two holes, about 3 inches diameter on top and tapering to about 1½ inches diameter at the bottom, in such a position as to get the powder into a joint of the rock (or a back, as the quarrymen term it), and of such a depth as to displace the stone from its natural bed below.

These holes are charged with a comparatively small quantity of powder in the first instance, for the purpose of opening up the natural joints and preparing the way for a heavier charge, which will displace the rock, and leave it in a fairly good position for further operations in cutting and dressing.

It may be that in some cases the same holes are fired several times before the final charge is put in, but this depends greatly on the position of the stone to be displaced, the angle of inclination of the lower bed, and the nature of its contact with the surrounding mass, if it has one or two free faces, &c. I need scarcely mention that the bore-holes are smaller in diameter at the bottom, not from choice but from necessity. It would be more advantageous to have the holes wider at the bottom, so that the charge may be placed as low as possible, but the steel drills used in boring wear so rapidly on the edges by friction, that in a hole, say 20 feet deep, the diameter at the bottom is only half of that on the surface. It is partly on this account that it is necessary to use a small charge in the first instance, so as to widen out the seams of the rock for the reception of a sufficient quantity of powder to loosen the rock.

In estimating the percentage of power utilised, as compared with the explosive force of the mixture, the following considerations have to be allowed for:—(1) incomplete combustion; (2) the compression, heating, and chemical change induced in the surrounding materials; (3) the escape of gas through the fissures of the rock, and the overturning power developed, which may be much more than is required for the actual breaking up of the rock.

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In some of the experiments before referred to, it was found that under the best conditions of a close cylinder, where the full amount of the heat was accurately measured, not more than 55 per cent. of the estimated heat of an explosive mixture of hydrogen and air was actually developed, and when the considerations just mentioned are taken into account it will be evident that a very much smaller proportion of the estimated pressure is turned into mechanical work. This percentage must also have a pretty wide range, as it is necessarily modified by the varying character of the rocks to be displaced which were before referred to. As examples of the wide difference which obtain in actual working, the following may be quoted :—

(1) A bore-hole, 12 feet deep × 4 inches diameter, filled to a depth of 6 feet with 30 lbs. of "rough blasting powder," dislodged 200 cubic yards of granite, being equal to 0·15 lb. of powder per cubic yard. This shot was fired in an open place, and was considered tolerably effective.

(2) Two bore-holes, 22 feet deep × 2½ inches diameter, charged four times with 25, 25, 25, and 350 lbs. respectively of "fine blasting powder," removed 410 cubic yards of granite, being equal to 1·04 lbs. per cubic yard. This mass of rock had only one open face, and the rock was rather tightly bound, although the angles of inclination of the sides were favourable.

(3) Two bore-holes, 22 feet deep × 2½ inches diameter, charged three times with 25, 25, and 15 lbs. of "fine blasting powder," dislodged 252 cubic yards of granite = ·79 lb. per cubic yard. This shot had only one open face, with a favourable position for removal, but the rock was cut off at a bed 17 feet below the surface of the ground, or 5 feet above the bottom of the bore-holes.

(4) Two bore-holes, 20 feet deep × 2½ inches diameter, charged seven times with 10, 15, 20, 40, 50, 75, and 250 lbs. = 460 lbs. in all, removed, but not efficiently, 400 cubic yards of granite = 1·15 lbs. per cubic yard. In this case the rock was very tightly bound, and developed in an unexpected manner, portions of the rock breaking up which appeared to be solid, and other portions coming out *en masse* where it was con-

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sidered there were evidences of flaws. No doubt, also, the fissures of the rock were too much opened up by successive blasts, so that the final charge was largely weakened by getting too many vents.

(5) A mine, $4\frac{1}{2} \times 2\frac{1}{2}$ feet, was driven into a face of granite 90 feet below the surface of the ground for a length of 42 feet, where an angle was made, and the mine then continued for other 25 feet, the extreme end of the mine being 50 feet from the face of the rock.

The whole mass of rock was entirely free on two sides. At the extreme end of the mine 2 tons of powder were deposited, and at the angle formed by the two headings other 19 cwts. were placed—the 25 feet of heading between the two charges was built up firmly with stones and cement, and the outer 42 feet of heading was hard rammed with stones and earth. The two charges were fired simultaneously from a battery, and the rock removed amounted to between 25,000 and 30,000 cubic yards. The stones were mostly of a very valuable character, and of very suitable sizes for handling in the quarry. The powder expended in this case would amount to from ·22 lb. to ·26 lb. per cubic yard.

It cannot be pretended that there is much in these practical experiments on which to found scientific data as to the explosive force of gunpowder—they were all carried out by men of large practical experience in the working of rock to be used for engineering or architectural works, and the considerations of the particular circumstances of each are so varied that it is very difficult deducing any general rule which may be followed in every case.

The principal differences in powder, apart from its chemical composition, arise from its density, the size of its particles, and the nature of its surface, rough or polished. The coarser varieties burn more slowly, and otherwise it varies in inverse proportion to its density.

2. Guncotton is formed from dry and clean cotton-wool (cellulose) by steeping perfectly in a mixture of one volume of nitric acid of specific gravity 1·5, and two or three volumes of sulphuric acid of specific gravity 1·85. The sulphuric acid does not enter into the chemical combination, but absorbs the

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water formed by the action of the nitric acid upon the cotton to allow of its proper nitration.

The composition of cellulose is approximately $C_6H_5(OH)_5$, and the action of nitric acid—

$$C_6H_5(OH)_5 + HNO_3 = C_6H_5(OH)_4NO_3 + H_2O,$$

and guncotton is approximately a nitrate of the form $C_6H_5(OH)_2(NO_3)_3$; it is thus a trinitrate, and it is perhaps never completely nitrated up to the formula indicated, but the finer the state of division of the cotton-wool to begin with, the more rapidly will the action proceed. The fibres are not changed to appearance, but they have increased greatly in weight by the substitution of 62 parts of NO_3 for 17 parts of OH.

Compressed guncotton has about the same weight as water.

It is doubtful whether the combustion is ever so perfect as to use up all the gases contained in the compound, the 11 volumes of oxygen would be insufficient to burn up the hydrogen and carbon, and the nitrogen never parts completely from the oxygen, but if it be assumed that the whole of the hydrogen is burnt up and both CO and CO_2 are produced the reaction may be stated as under:—

$$2[C_6H_5(OH)_2(NO_3)_3] = 7(H_2O) + 3(CO_2) + 9(CO) + 6N,$$

giving 44 volumes of gas $= 44 \times 11{\cdot}2 = 492{\cdot}8$ litres.

The weight of the compound $= 594$ grammes.

$\therefore \frac{492{\cdot}8}{{\cdot}594} =$ expansion of 829 volumes of gas at 0° C.

The temperature produced by the explosion would equal 5268° C. Dividing this number, as in the case of blasting powder, by 273°, we have $\frac{5268^\circ}{273^\circ} = 19{\cdot}3$ times the increase of bulk by rise of temperature. $829 \times 19{\cdot}3 = 16{,}000$ times the original bulk of guncotton.

These figures would seem to show that the power of guncotton, as compared with gunpowder, was as $2\frac{2}{3}$ to 1, but there is a marvellous difference in the manner of explosion. While in the case of gunpowder the ignition takes place from particle to particle, by a process of combustion, guncotton is

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detonated; that is, the resolution of the particles is due to an instantaneous shock, where a molecular rearrangement takes place, producing the same amount of heat as the slower combustion by ignition would produce in another way. The velocity of the explosion of guncotton ignited but not detonated has been set down by Piobert as eight times that of gunpowder, and another author (Mr C. Napier Hake), in the *Journal of the Chemical Society*, states that the velocity of the explosive wave in detonating guncotton has been ascertained to be from 5000 to 6000 metres per second. Guncotton used in exploding a shell is found to have three times the power of an equal charge of powder, which corresponds very nearly to the ratio we found by volumes of the cold gases, viz., $\frac{829}{332}$.

If detonated, guncotton would have 6·5 times the power of gunpowder.

Guncotton as manufactured appears to be deficient in oxygen to burn up the carbon and hydrogen completely, and hence in the varieties used in mining, some nitrate is always added to supply this defect.

"Tonite" is a compound of guncotton in which nitrate of barium is commonly mixed to give a full supply of oxygen to the guncotton or cotton-powder.

Guncotton impregnated with water or with paraffin becomes insensible to a shock from an ordinary detonator, but it can be exploded though quite wet or even under water by placing a small charge of dry cotton on the top of it encased in a water-tight wrapper.

3. Nitroglycerine was known to chemists as a great explosive force more than fifty years ago; but from the fact that it could not be ignited or exploded with a spark, and the blow of a hammer only produced a local detonation, its great use as an explosive was not discovered until twenty years later. There was also difficulty and danger in its manufacture which prevented its coming into common use. It was first introduced into Sweden in November 1864, when a company was formed for its manufacture, and between February 1865 and August 1866 22,217 lbs. were sold.

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When used for blasting, it was poured carefully into the bore-hole, either through a tube, or was allowed to trickle down a small iron or wooden rod to prevent any sudden shock arising from its falling to the bottom of a deep hole. The charge was detonated by a small capsule containing fulminate of mercury, or by a capsule attached to an igniter which was simply a case containing a small portion of powder, and in either case attached to an ordinary time fuse as used in blasting with powder. For filling up the remainder of the bore-hole, water tamping was preferred, as the oil was insoluble and heavy (specific gravity 1·60), so that the water did not sink in or unite with it.

In cases where the bore-holes were inclined, or in an upright position, as in the roof of a tunnel, the nitroglycerine was encased in an india-rubber bag, and sand tamping was then used. It did not require to be tightly held in, as the reaction was so violent that the filling up or leaving open of the bore-hole had very little influence in increasing or diminishing its useful effect. Nitroglycerine is formed by the action of nitric acid on glycerine, a compound containing $C_3H_8O_3$, or, as it is preferred by some chemists to designate more particularly its alcoholic construction, 3 parts of OH formation are separately written, taking the place of three of the hydrogen atoms,—thus, $C_3H_5(OH)_3$.

This substance, treated with nitric acid, would give:— $C_3H_5(OH)_3 + HNO_3 = C_3H_5(OH)_2NO_3 + H_2O$. But to remove the water formed by this process, and to allow the full nitration to proceed, sulphuric acid is used in this case in the same way as in the manufacture of guncotton. The usual method of preparing nitroglycerine is to mix the two acids first, and allow them to thoroughly cool down before adding the glycerine.

The glycerine must then be added in drops or in fine spray to prevent any increase of temperature, which might have the effect of producing nitric peroxide (NO_2), which would inevitably cause an explosion.

When the process of nitration is completed, it will be indicated by the decrease of temperature in the mass, showing that chemical action has ceased, and the nitroglycerine

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(specific gravity 1·6) will float on the top of the acid solution; when poured off, it is well washed with water and an alkaline solution to remove the last trace of acid. The acids and glycerine employed in the process must be perfectly pure, and the quantities used in one mixing are approximately:— Nitric acid (specific gravity 1·5), 1·2 tons; sulphuric acid (specific gravity 1·84), 2 tons; and glycerine (specific gravity 1·26), 7·5 cwts. By the chemical equation, every lb. of glycerine should produce 2·47 lbs. of nitroglycerine, but in practical work it is only a little more than 2 lbs.

Its composition may be taken as $2(C_3H_5N_3O_9) = 5H_2O + 6CO_2 + N_6 + O = 29$ volumes. 29 volumes × 11·2 litres = 324·8 litres. The weight of the compound = 454 grammes, and specific gravity being 1·6, the bulk is $\frac{454}{1·6} =$ 284 litres.

$\therefore \frac{324·8 \text{ litres}}{284 \text{ litre}} =$ expansion of 1144 volumes of gas at 0° C. The increase of temperature produced by the explosion would equal 7683° C. nearly.

$\frac{7683°}{273°} = 28·14$ times the increase of bulk by rise of temperature, and $1144 \times 28·14 = 32,192$ times the original volume of the nitroglycerine.

Owing to the danger in working and handling nitroglycerine, its use never became very general in this country, and many attempts were made to render its transit more safe. One proposal made by Nobel, whose name is well known in connection with the history of this compound, was to dissolve the nitroglycerine in twice its bulk of methylic alcohol or wood spirit (CH_3HO), thus producing an inexplosive liquid. The spirit and nitroglycerine could afterwards be easily separated by treating it with water and stirring up. The nitroglycerine sinks to the bottom, and can be obtained pure by decanting the water and alcohol.

But a much better solution of the difficulty was soon after discovered by Nobel, who, in 1867, produced dynamite, which is simply nitroglycerine absorbed by a porous substance, such as silica, charcoal paper, or similar materials. Since the time

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of this invention great numbers of different compounds have been formed with nitroglycerine.

4. Dynamite No. 1, as it is called, consists of 75 parts by weight of nitroglycerine and 25 parts kieselguhr, the latter being an inert base for absorbing the nitroglycerine. It is composed of the mineral remains of a species of moss which grew in stagnant waters. The stem consisted chiefly of silica, and when the organic substance of the plant decayed the siliceous portion remained, retaining the shape it had when it formed a part of the plant, that is, a series of cells or diatoms. This earth has the power of absorbing in its cells three times its own weight of nitroglycerine, and develops a power proportional to the weight it has absorbed of that substance. A particular point in the mixture is, that there must be no hard substance in the composition amounting to grittiness so as to cause friction, and slightly charred cork is an excellent substance to use for this purpose.

Dynamite is not so sensitive to shock as nitroglycerine, and detonators of a much higher power are required to explode it. When frozen it is less sensitive even than when in its ordinary plastic condition, but it is much more dangerous to handle in the hard state as it does not accommodate itself so readily to the shape of the bore-hole as the plastic material. Until the introduction of other compounds of nitroglycerine, dynamite was considered a perfect blasting material, both for its great strength and safety. It was known that there was occasionally danger arising from the nitroglycerine oozing out of the compound, and that its effects under water were sometimes not so effective owing to this reason.

Another great step was taken in advance when nitroglycerine came to be mixed with cellulose or cotton, a substance was then produced having no inert body in its composition, but forming a perfect chemical compound in which the whole substance was completely exploded. Such a substance is—

5. Blasting Gelatine, which consists of a combination of nitroglycerine and nitrocotton. Guncotton cannot be dissolved directly by nitroglycerine, but when dissolved in acetone it may then be combined mechanically with nitro-

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glycerine, and one of the products of this mixture is blasting gelatine.

It is a tough, slightly elastic, semi-transparent substance containing 93 per cent. of nitro-glycerine and 7 per cent. of nitrocotton. Its specific gravity is 1·55 to 1·59, and the products of combustion on explosion are put down as CO_2H_2O and N. Its disruptive force is set down as 50 per cent. greater than dynamite as proved by the ballistic test.

6. Gelatine Dynamite is another nitroglycerine compound, and occupies an intermediate position between blasting gelatine and dynamite. It consists of nitroglycerine, 80 per cent.; nitrate of potash, 14 per cent.; and wood meal, 6 per cent. It is much slower and less violent in its action than blasting gelatine, and its relative force is set down as from 30 to 40 per cent. greater than dynamite. Its later form of "Gelignite," containing 60 per cent. of nitroglycerine, is now in such demand as being the most useful for such a variety of purposes, that it bids fair to displace nearly all other compounds where a strong and disruptive force is required.

It would be useless to attempt in one short paper to describe the explosives now in use or proposed to be used. The samples given occupy the leading place meantime for the work of rock-blasting, although such explosives as "Roburite," consisting of, by analysis—

Nitrate of ammonia,	82·0
Dinitrobenzol,	16·7
Moisture,	1·3
	100·0

and "Ammonite," consisting of, by analysis—

Nitrate of ammonia,	90·0
Nitronaphthaline,	10·0
	100·0

may, with some modifications in their composition, come to be found useful for certain work.

Both these compounds claim to be flameless powders, and for this reason it is contended they are safer for use in coal mining operations where there is danger of any escape of gas from the coal. But authorities are not yet agreed that this point is fully proved.

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Ammonite is made up as a loose powder packed in thin lead cylinders coated with paraffin wax, having a small projection at one end intended to be cut off for the insertion of the detonator.

Owing to its low specific gravity (·88), and the cost of the necessary metallic coating, it will be difficult to bring it largely into competition with other explosives now in use, unless some super-excellent qualities are developed to enable it to overcome these disadvantages.

Repeated reference has been made to detonators during the paper, and it may be well in a single sentence to note their composition, and why they are so eminently suited to give the initial shock of an explosion.

In preparing fulminate of mercury, 3 parts of mercury are dissolved in 36 of cold nitric acid, specific gravity 1·34; to this 17 parts of absolute alcohol are added, and as violent action begins, 17 parts of alcohol are poured in. The precipitate, $C_2N_2Hg.O_2$, formed varies from gray to white, which is washed in cold water, purified by dissolving in hot alcohol, and crystallising. If used pure it would be too sensitive to shock, and hence it is mixed with ground glass powder to dilute it. The products of combustion are $Hg.N_2 2(CO)$, and it is said to detonate within its own volume 40,000 atmospheres. This enormous pressure produced instantaneously develops such heat as to resolve the nearest layers of explosive into gas; and as these in their turn develop additional heat, the explosion is propagated through the whole mass.

Owing to its great density, its instantaneous decomposition, even when slightly confined, and the almost total absence of dissociation products, it is the most suitable for producing the initial shock. If the fulminate were placed in a goose quill instead of a copper tube, the effect would be practically deadened if fired in the open air.

Much interesting information has been gathered from the study of the detonating influence in various explosions.

For example, a line of dynamite cartridges laid along the ground may be detonated from one end, and it is calculated that if they were a mile long, and detonated from both ends, it would only occupy one-fourth of a second to detonate them all.

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On the other hand, there are great differences in explosive substances for communicating and receiving vibration. Nitroglycerine may be detonated on the top of guncotton without exploding it, whereas guncotton detonated on nitroglycerine never fails to bring about an explosion. This may be explained by the difference in the structure of the substances, or it may be the velocity of the explosive wave being so incomparably more rapid in guncotton than in nitroglycerine. In the case of the latter it is put at 5000 to 6000 metres, but in guncotton it is said to be 56,000 metres per second. These measurements may not be accurate, because authorities differ; but if they are partially correct, the different effect may be sufficiently accounted for.

Guncotton, nitroglycerine, dynamite, gelignite, roburite, &c., all differ in respect to the strength of the detonators required. A fulminate of mercury cap, with a charge of ·25 gramme, is not sufficient to explode dynamite—the full intensity of a charge of ·56 gramme, and for gelignite a charge of ·8 gramme, being necessary.

The theory of synchronous vibrations has been suggested to account for the phenomena of detonation, and experiments have been made to prove it.

A few particles of nitrogen iodide, a substance which detonates on the slightest friction, were attached to the strings of a double bass, and the strings of a similar instrument were made to vibrate at a short distance.

The result was a detonation, but only for sounds higher than a note corresponding to 60 vibrations per second. A similar experiment was made by detonating a drop of nitroglycerine at one of the foci of a parabolic reflector when a drop was exploded in sympathy at the other foci, to the exclusion of other drops on the same line placed at other points.

In determining the most suitable explosive for any particular work, it is necessary not only to discover its force when developed, but the velocity with which that force is developed. If it is given off in a second, $\frac{1}{100}$th or $\frac{1}{10,000}$th of a second, it will vary greatly in its effects, its power being inversely proportionate to its time of development.

In destructive rock-blasting, where the rock is very hard,

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and the main object is the removal of the material, the more powerful explosives are almost invariably the most successful. There is an immense saving in the boring of smaller holes and having fewer charges than with the weaker compounds.

The mechanical equivalents of various explosives are thus stated by Roux and Sarrau: —

	Theoretical Work in Kilos.	Relative Value.
Blasting powder with 62 per cent. KNO_3,	242,335	1·0
Dynamite with 75 per cent. nitroglycerine,	548,250	2·26
Blasting gelatine with 92 per cent. nitroglycerine,	766,813	3·16
Nitroglycerine,	794,563	3·28

and the following figures have been given by Berthelot as volumes of gaseous products for 1 kilo. of solid or liquid explosive, which confirm to some extent the decompositions we have endeavoured to explain: —

	Litres of Gas calculated.	Pressure, Grms. p. cm.
Black powder,	270	2,190
Mercury fulminate,	314	6,200
Guncotton,	859	10,000
Nitroglycerine,	713	10,950

It is estimated that not more than from 16 to 33 per cent. of the theoretical volume of gas produced is available for useful work.

ENERGY OF EXPLOSIVES.

Quantity of Explosive used in Mortar, ... 10 Grammes.

Name of Explosive.	Ingredients.	Per-centage.	Energy in ft.-pounds.
1. No. 1 Dynamite	Kieselguhr Nitroglycerine	25 75	920
2. No. 1 Blasting Gelatine	Nitroglycerine Nitrocotton	92 8	1410
3. Nitroglycerine	Nitroglycerine	100	1266
4. Gelatine Dynamite	Nitroglycerine, 92·3 % Nitrocotton, 7·7 % Nitrate of Potash Wood Meal	80 14 6	1213

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ENERGY OF EXPLOSIVES—*continued.*

Name of Explosive.	Ingredients.	Per-centage.	Energy in ft.-pounds.
5. Gelignite	Nitroglycerine, 94·85 %	60	1013
	Nitrocotton, 5·15 %		
	Nitrate of Potash	28	
	Wood Meal	12	
6. Detonator Mixture	Chlorate of Potash	20	536
	Fulminate of Mercury	80	
7. Fulminate of Mercury	Fulminate of Mercury	100	327
8. Ammonia Powder	Nitrate of Ammonia	91·28	790
	Wood Meal	5·72	
	Sulphur	3·00	
9. Nitrate of Ammonia Powder	Nitrate of Ammonia	69·43	880
	Picric Acid	30·57	
10. Nitrate of Potash and Picric Powder	Nitrate of Potash	53·55	650
	Picric Acid	46·45	
11. Nitrate of Soda and Picric Powder	Nitrate of Soda	72·13	360
	Picric Acid	27·87	
12. Nitrate of Soda and Picric Powder	Nitrate of Soda	49·12	680
	Picric Acid	50·88	
13. Nitrate of Soda and Picric Powder	Nitrate of Soda	44·59	670
	Picric Acid	55·41	
14. Nitrate of Ammonia and Ferrocyanide of Potassium	Nitrate of Ammonia	72·29	850
	Ferrocyanide of Potassium	27·71	
15. "Securite"	Nitrate of Ammonia	82·64	970
	Dinitrobenzol	17·36	
16. Nitrate of Potash and Dinitrobenzol	Nitrate of Potash	66·79	550
	Dinitrobenzol	33·21	
17. Chlorate of Potash and Dinitrobenzol	Chlorate of Potash	70·86	815
	Dinitrobenzol	29·14	
18. Chlorate of Potash and Paraffin	Chlorate of Potash	89·0	670
	Paraffin	10·60	
19. Chlorate of Potash and Dinitrocotton	Chlorate of Potash	53·16	920
	Dinitrocotton	46·84	
20. Dinitrocotton	Dinitrocotton	100	550
21. Maxim's Powder	Nitrate of Potash[3]	78·18	200
	Sulphur	10·40	
	Paraffin	11·42	
22. Gunpowder	Gunpowder $\frac{R L G^2}{A}$	...	335
23. Gunpowder	Gunpowder $\frac{R L G^2}{D}$	...	347
24. Gunpowder	Gunpowder $\frac{R L G^2}{F}$	...	362
25. Gunpowder	Gunpowder Brown $\frac{C}{H}$	...	174
26. Vul Powder—Blasting	Ferrocyanide of Potassium	82·06	406
	Nitrate of Potash		
	Solid Paraffin	4·78	
	Peroxide of Iron	1·14	
	Charcoal	12·02	
27. "Roburite"	Nitrate of Ammonia	82·0	950
	Dinitrobenzol	16·7	
	Moisture, &c.	1·3	
28. "Tonite"	Guncotton	50·20	820
	Nitrate of Barium	47·40	
	Carbonate of Soda	72	
	Moisture	1·54	
29. "Potentite"	Guncotton	59·60	840
	Nitrate of Potash	36·80	
	Moisture	2·75	
30. Gunpowder (for Cannon)	Gunpowder	...	440

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On Safety-cage for Miners, and Hoists generally. By JOHN WHITELAW, C.E. and M.E., M.F.I.M.E.* (With Plate.)

Mr President, Vice-presidents, and Gentlemen,—In introducing this apparatus to the notice of this Society, which has been designed for the prevention of accidents arising from the breaking of ropes or chains and from overwinding, we venture to think the necessity for having some such contrivances as here to be described will be obvious, when considering the number of accidents and loss of life and injuries that are being recorded as occurring by ropes, &c., breaking. From 1857 to 1868, or a period of twelve years, the average annual loss of life was about 24 from the before-mentioned causes.

This is not to be wondered at when 300,000 men, on an average, had to descend and ascend pits daily to their work at that time. In 1890 this had increased to nearly 532,000; and at this ratio of increase there will now be about 600,000 employed underground.

Assuming these require to be lowered and raised at the pits, say 250 times a year, it would be equal to 300,000,000 separate times, and that from pits averaging in depth from 40 to 800 yards. In Belgian pits, for instance, which are much deeper, risks become greater; there the average of 258, in the district of Charleroi, was 547 yards, while the deepest is 921 yards. At Montigny-sur-Sambre there is one 1041 yards deep.

The descent and ascent of pits of such depths is undeniably a dangerous operation, and the wonder is that so few accidents and loss of life occur, considering the dangers and risks attendant thereon.

Many accidents have also occurred with hoists employed for raising and lowering persons in hotels and other establishments where these are used instead of stairs; now, these hoists, we think, ought all to be provided with safety apparatus. Further, we maintain it would also be economical were the same provision made where goods are similarly raised and lowered.

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* Read before the Society, 14th March 1892.

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With these preliminaries as to the necessity for the adoption of safety appliances, we shall now describe the arrangements, principles, and action of the cage now submitted as suitable and simple, to aid in preventing accidents where cages and hoists are used. They consist in the arrangement of levers L.L., springs S.S., and grippers G.G., and of rods instead of chains, but more particularly of the teeth of the grippers on the ends of the levers, to be afterwards described. The grippers or catches are brought into play—should the rope break or the cage be disengaged by the detaching apparatus in case of overwinding—by the strong blade-spring S.S. (similar to coach or waggon springs), fixed to a centre bar, and to which it is secured with glands, and on which it is also supported; provision is made for adjusting said spring, which is easily done by inserting a piece of leather under it, after which it is not liable to derangement.

There is also a strong circular iron cover as a protection against things that might fall down the shaft.

The disengaging apparatus is simple, and is brought into action only if drawn up through the iron ring shown, which compresses the two sides, these sides being held out by a spring S. and two small copper pins. Should the cage be overwound, and the disengaging apparatus be forced through the ring, the small spring is compressed and copper pins cut by the shearing force, and the cage becomes detached, but it would be arrested by the gripping catches taking hold of the timber guide-rods and thereby suspended.

The principle of the action of these toothed grippers G.G. may be illustrated with a joiner's chisel; if, on applying it with the bevelled side next to the guide-rod or a piece of timber, it will be found to thrust outwards, cutting and carrying a portion of the timber before it; now reverse it, and its tendency is to cut into the timber and hold fast, so with the teeth of the grippers, when brought into contact with the guide-rods by the spring S.S. and the weight of the rods R.R. and cage, acts by pressing the levers and grippers against the sides of the guides in nearly opposite directions, and thus suspends the loaded cage.

Two cages of the construction described were in daily use

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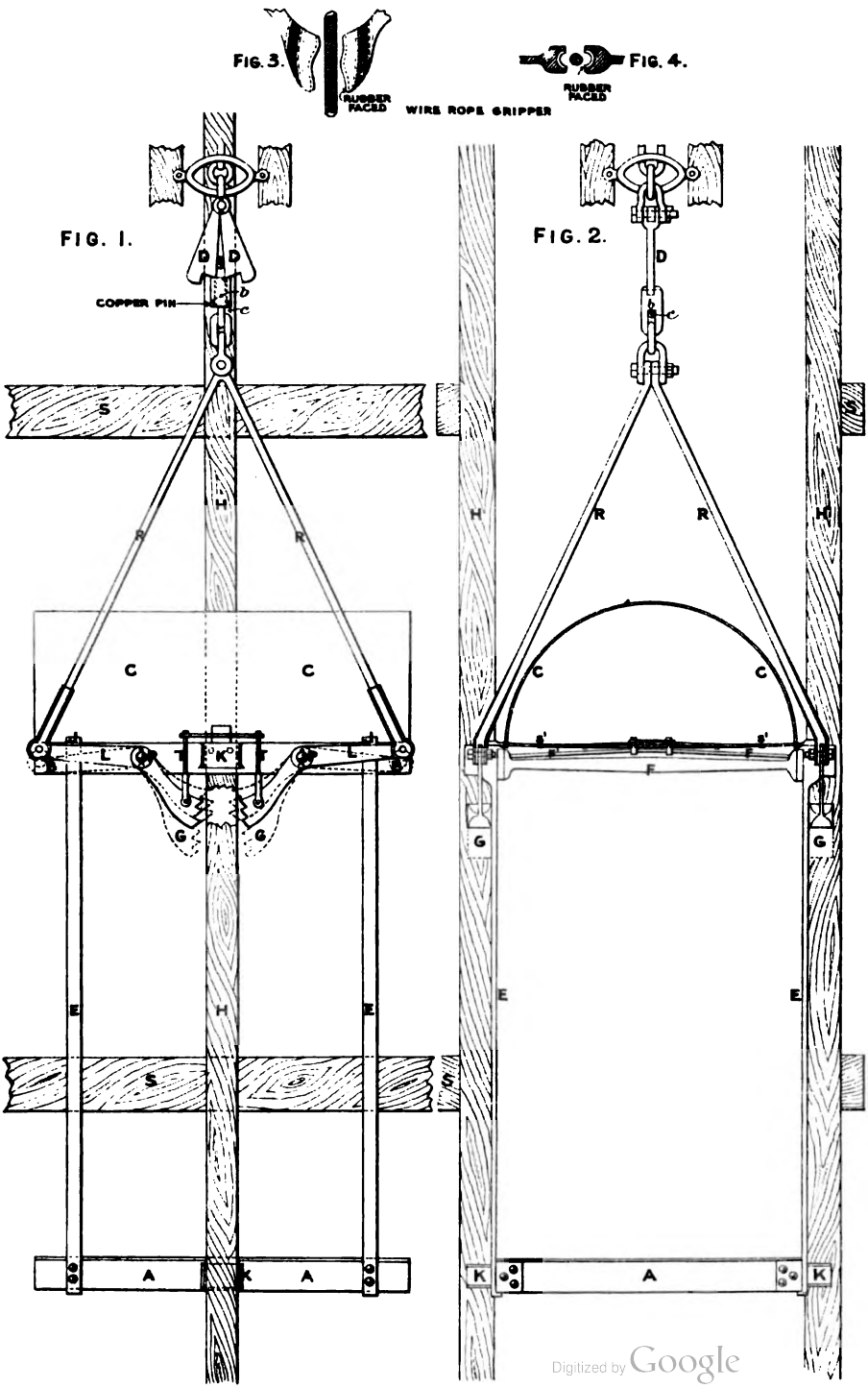
To illustrate Mr. John Whitelaw's Paper on "A Safety Cage for Mines & Hoists."



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for eight years at Prestongrange Colliery (Sir G. Grant Suttie's), one of these being practically tested owing to a rope breaking when the cage and load was arrested at 90 yards from the surface and 50 yards from the bottom; it had only fallen 2 inches, and there hung until a new rope was attached and it drawn to bank. There was no damage done to the guides.

It is a matter of surprise to us that safety-cages have not been made compulsory by our Government, both for mines and wherever hoists are used for lowering or raising persons, as many, if not all the loss of lives from such accidents, arising from want of their use, might have been averted. In America we understand it is compulsory. Railway companies here are obliged to use safety-brakes, and why not in cases of hoists?

REFERENCE TO PLATE.

A.A. Framing of bottom.
B.B. Side bar of top frame, on which levers L.L. are fixed.
C.C. Cover to guard against stones falling down shaft.
D.D. Disengaging and non-disengaging catch, in case of overwinding, which is so arranged as to relieve the catches C.C. in passing through the ring above; the catches, when passed through the box *b*, are put and kept in position by the spring S.², and may, if necessary, be further secured with copper-pins.
E.E. Bars, connecting bottom and top frames.
F. Front bar of top frame.
F'F'. Bar on which spring S'.S'. is carried.
G.G. Grippers in which the efficiency and novelty of this cage is brought into action by spring S.S. and connecting-rods T.T., assisted by weight of the lifting rods R.R. The teeth are so arranged as to dig simultaneously into the guide-rods; they may be increased as shown by the dotted lines.
H.H. Guide-rods.
J.J. Stops preventing levers from being lifted above the horizontal, or overstraining the spring.
K.K. Guides which work on rods H.H.
P.P. Studs whereon levers work.
L.L. Levers with toothed grippers G.G., which dig into the guide-rods H.H., as shown by black dotted lines, if the rope breaks or the cage be disengaged.
S.S. Struts or "buntins."

N.B.—Catches for wire or other rope guides are shown on Plate, which have been added since the Paper was read.

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Electrical Pumping and Haulage. By E. A. BROWNING, A.I.E.E.*

In this paper no attempt is made to enter fully into this very important subject, as the time at disposal is not nearly sufficient to treat the subject adequately; but two applications are taken, viz., that of pumping and of lighting, in order to bring the subject under the observation of the Society.

The latter is treated upon first, and a new type of miner's lamp was shown weighing just 7 lbs., and capable of giving a light equal to about two candles continuously for eleven to thirteen hours. This lamp, both as regards weight and capacity, is a decided improvement upon former productions.

The author also states that electricity has had extensive application for the lighting of the "roads" underground, and instanced the installation at the Newbattle Collieries where the light has been in use for some five or six years, and where it is also used for lighting a new shaft which is being sunk.

In introducing the subject of pumping, the author compared the ratio of progress of the application of steam and electricity, and called attention to the very close alliance which exists between them. It was pointed out that steam is essentially a prime mover, coal being the source of energy, whilst electricity is essentially a secondary power, being a medium through which energy is transformed into light and heat, or into power—usually at some considerable distance from the source.

It was also shown that electricity is a very efficient converter of energy, dynamos and motors being commercially made with efficiencies ranging from 85 to 94 per cent.—which is very near perfection.

A short history of electrical pumping was given, which dated back as far as the year 1882, when a small electric pump was started in a colliery in the Forest of Dean.

The first pump started in Scotland was stated to have been set to work at the Ormiston Collieries in January 1891, and a full description as it appeared in *Electrical Plant* of December 1891 was read.

* Read before the Society, 25th March 1892.

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The description was written by the proprietor of the colliery, and stated that the cost of the pump was much less than a steam plant would have been, and its maintenance cost 4·8 pence per hour, which is about one-third the cost of steam.

Another pump, and a larger one—of 20 H.P.—at the Newbattle Collieries was also described, and the results of exhaustive tests were given which showed an overall efficiency, from the steam-engine cylinder to the water delivered, of 44·4 per cent.

The water delivered was 3000 gallons per hour through a vertical height of 960 feet, which represents a pressure of nearly 500 lbs. per square inch. The delivery pipe was about 600 yards long.

Finally, the advantages claimed for electricity over other methods of power-transmission, such as steam, compressed air, rope, and hydraulic, were summed up as follow:—

1. Greater efficiency.
2. Smaller capital expenditure, especially when the distance of transmission is great.
3. Greater ease in manipulation.
4. Smaller ground-space occupied.
5. Absence of heat and vitiation of air.
6. Less cost of maintenance.

Then mention was made of other electric pumps at the Arniston Colliery and the Whitehill Colliery, which the author had erected.

The Application of Electricity to Hoisting Machinery.
By JOHN RITCHIE, C.E.* (With Four Plates.)

The use of hoisting machinery is now universal, and owing to the gradually increasing value of manual labour, some mechanical power is becoming more and more a necessity. The question then, for those who have to use power hoisting machinery, becomes, what is the best method of applying that power? To apply steam direct to the gearing of cranes through suitable steam-engines is a usual way (engines and

* Read before the Society, 25th March 1892.

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boiler moving with, and forming part of, the structure), and it has many good points to recommend it.

But the purpose of this paper is to show the superior advantages of the application of electricity over the direct use of steam, and other methods of transmitting power to cranes. It is taken for granted that the electricity supplied to the crane-motors is generated in the first instance by steam; and as their use is as yet somewhat limited, it was natural that they would be first adopted in those works or factories which possessed an electric plant for lighting purposes. With an existing plant it became a comparatively easy matter to apply part of the current to drive cranes or other machinery. It seems, however, only a question of time, when every work shall possess such a plant, and thus be able to distribute power, from its centre to the most distant machine, with an economy hitherto unheard of.

The modern electromotor is a highly efficient machine, and in transmitting power its efficiency rises as high as 90 per cent. It is not, as many suppose, a complicated and delicate machine, but one capable of continuous running under varying loads, and easily understood by an ordinary mechanic; and, as to durability it will compare very favourably with a steam-engine.

In small installations in which the dynamos are driven direct by steam-engines, 80 per cent. of the useful effect of the steam-engine is given out by the dynamo. And with a large and economical engine, driving machinery in a workshop, where the power expended on the dynamo would only be a fraction of the whole, the useful effect would be still greater, say 85 per cent.

The loss in transmission would not exceed 2 per cent., if the cranes to be driven were within a reasonable distance of the generating plant. The figures would, in ordinary circumstances, stand thus:—

10 H.P. put into dynamo gives out, . .	8·5 H.P.
Loss in transmission, 2 per cent. = . .	·17 „
Power put into motor = ...	8·33 „
Power from motor at 90 per cent. eff. = .	7·49 „

Or a total loss of 25 per cent.

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An ordinary steam-crane does not show such an economical result as this.

A 5-ton crane of ordinary constructure with a pair of 6-inch cylinders, steam cut off at $\frac{3}{4}$ stroke, uses about 40 lbs. of steam per hour, and a total efficiency of 60 per cent. is extremely rare. The vertical boiler generally used is of a very wasteful type, and uses 6 to 8 lbs. of coal per horse-power per hour. There is also the constant loss of heat from radiation, as, owing to the intermittent nature of the work required from cranes, steam has to be kept up whether they are at work or not.

In the case of a workshop electrical installation, however, we have generally an economical form of engine and boiler, and the generating dynamo and motor on the crane only consume power equal to the friction of their armature spindles, and the small current required to excite them, when the crane is doing no work.

Overhead travelling cranes have hitherto been almost invariably driven by high-speed ropes, or from a line of square shafting. In both forms a large proportion of the power required is consumed in merely driving the rope or shaft. Take the case of an overhead crane of, say, 10 tons power in a shop 200 feet long, the rope is driven at 4000 feet per minute. The power required to drive the rope alone, and overcome the friction of the guide, pulleys, and resistance to the air, is 8 horse-power.

This consumption of power is constant whether the crane is in use or not, and as the actual proportionate time that a travelling crane is doing work, even in a very busy workshop, is, on an average, not more than 20 per cent. of the total time, the loss is easily seen. The same applies to shaft-driven cranes; the power required to keep in motion at 150 revolutions, say, 200 feet of $2\frac{1}{2}$ shafting, including the side shafts of crane, is 6 horse-power. In fact, the power required to drive the rope or shaft often exceeds that required to raise the average load on the crane.

This power is saved by the application of an electromotor, as the actual power required is just that necessary to overcome the inertia of the load plus the friction in motor and crane gearing.

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The drawings A, B show the general arrangements of 10-ton electric-cranes, having a span of 45 feet. The general design of the crane as designed and constructed by the writer is similar to that in use for rope driving, and consists of two steel girders fitted to two cast-iron end carriages fitted with wheels and axles. The crab which travels on the top of the two girders contains the hoisting gear, and is fitted with two speeds of lift—one at 4 feet per minute, and another for light loads at 20 feet per minute. The longitudinal travelling speed of the crane is 55 feet per minute, and the cross travel of crab 40 feet per minute.

The motor is mounted on one of the end carriages, about the centre of its length, and the power is taken from both ends of the armature shaft, through flexible couplings, and thence by three sets of frictional bevel wheels to shafts driving the hoisting, longitudinal, and cross travelling motions.

The frictional bevel gear is a special feature of these cranes. The proportion of this gear is 3 to 1, and the pinion or driver is double, and consists of a sleeve of cast iron sliding on a feather, the bevelled or conical portion is formed of layers of compressed paper held in position by a collar and large screwed nut. This is easily renewed when worn, but in practice has been found extremely durable.

The double cone is pressed against the large iron disc by the action of a lever, and by moving this lever in opposite directions, the crane raises or lowers the load. The same arrangement applies to the travelling motions, and the whole working of the crane is under the complete control of the driver who is perched in the cage under the crane beams. All the three motions may be at work simultaneously.

The motors are shunt-wound, and they run at an approximately constant speed with a varying load, the normal speed being 1200 revolutions per minute. The voltage is 110. The machine has double-field magnets, the cores of which are of annealed wrought iron fixed by bolts and nuts into a recess formed in the end carriage of the crane. The coils are wound on four bobbins, and connected in such a manner that the two coils on the same magnet-limb have their similar poles

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adjacent, the pair on the one side having their north poles, and that on the other side their south poles adjacent, so that the lines of force pass horizontally through the armature from, and into those portions of the vertical limbs between, the coils, which portions therefore form the pole pieces.

The object of this form of construction was to make the motor as narrow as possible, and by occupying a small space allow the crab with the lifting chain to come as near the end of the crane as possible. In order to facilitate the removal of the armature, should this be necessary, the magnets are parted in the centre and connected together by outside plates and screws.

The armature is of the drum type, the spindle being extra strong, and a special mode of fixing is adopted at the commutator end, so that the rather unusual mode of driving from both ends may be used with safety.

The current is conveyed to the motor through a naked wire $\frac{3}{16}$ inch in diameter, stretched tight overhead, and supported at intervals by light hanging wires. It is picked up, as the crane travels along, by a sliding shoe pressed against the under side of the wire by a spring. The return current is taken back to the dynamo by a similar wire stretched overhead at the opposite end of the crane, the object of having them so far apart being to prevent any possibility of short circuiting.

I have stated that the speed of the motor was only approximately constant, and this in a crane is an advantage, as it gives a moderate range of speeds of lifting, according to the load, without altering the gearing of the crab, it occurs in this way:—Suppose a constant potential is maintained at the terminals of the motor, the strength of the field magnets is also constant, because the current through the coils will always be the same, but the speed of rotation regulates the current through the armature; when, therefore, a heavy load comes on the crane chain, and thence through the gearing to the armature, the tendency is to reduce the speed of the latter, this allows a stronger current to pass through it, by reducing the counter EMF, giving the electric power necessary to overcome the load just when it is most wanted. With a light load, however, the tendency is for the speed to

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increase; the counter EMF rises also, allowing very little current to pass through the armature, and a very slight expenditure of electrical power takes place.

It will thus be seen that the machine automatically regulates itself, and takes only the power required to do the work.

In travelling cranes it has been found better to keep the motor constantly running in one direction, the reversing motion being obtained from the frictional bevel wheels beforementioned.

Worm gear is introduced to reduce the speed between the motor and crab gearing, and although this involves the loss of considerable power from friction, it has the advantage of absolute safety.

The motors for these cranes were manufactured by the Electric Construction Corporation of Wolverhampton. The cranes have now been at work nearly two years, and the cost for repairs has been practically nil.

Ten-ton Travelling Crane.

	Feet per Minute.	Volts.	Ampères.	E.H.P.
Empty—				
Travel up and down shop,	50	109	28	4·08
Cross travel,	50·2	109	22	3·21
Lift,	8·9	114	28	4·28
	4·3	109	25	3·65
Lower,	8·9	114	18	2·75
	4·3	109	18	2·63
With load of 6 *tons* 12 *cwt.*—				
Travel up and down shop,	49·3	109	30	4·38
Cross travel,	50·2	109	35	5·11
Lift,	4·3	106	90	12·78
Lower,	4·3	108	36	5·21
With load of 8 *tons* 12 *cwt.*—				
Travel up and down shop,	49·3	112	35	5·25
Cross travel,	50·2	112	35	5·25
Lift,	4·3	103	130	17·94
Lower,	4·3	110	60	8·84

The power required for the work in the above table may appear somewhat large, but the crane was new, and all the bearings a tight fit, a reduction of 20 per cent. in friction may be assumed to take place after the crane has been at work a short time.

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For lighter cranes a slightly different design is preferred, and the arrangement adopted in several 3-ton travelling cranes now at work near Leeds has been most satisfactory.

The motor is fitted in much the same way as in the 10-ton crane, but the gearing for hoisting, instead of forming part of the travelling crab, is all fixed at one end of the crane, and a simple travelling carriage, with guide pulleys for the hoisting chains, travels on the beams. No barrel is used, but a pitch chain and toothed pulley, the loose chain passing into a tank. This design enables the crane-hook to be brought to within 30 inches of the end of crane. The longitudinal speed of travelling is from 70 to 80 feet per minute, and the cross travel 50 feet per minute.

Fig. C shows the arrangement of starting switches and resistance board, which, owing to the varying character of the work these cranes have to do, it was considered advisable to apply.

The object of the resistance board is twofold, it serves to vary the speed by reducing the current in the armature, and in the second place, it prevents a very large rush of current through the armature when it is at rest, and until such time as it shall have attained a speed which enables it to generate an opposing EMF sufficiently large to regulate the current flowing through the armature from the generating dynamo. The switches, and the various motions of this crane, are all controlled from the floor.

The ordinary steam derrick-crane is familiar to everyone, and in our large cities a very dangerous looking object it is, perched on a scaffold 50 or 60 feet high with its long jib or derrick stretched out over the street. The steam derrick-crane has been an enormous boon to the builder and contractor, enabling him to execute work in a space of time that would, a few years ago, have been thought marvellous. There are certain drawbacks to its use, however, and these are in great measure connected with the boiler. This in itself is a considerable weight, and takes up a good deal of room, all the water and coal for its use have to be taken to the top of the staging. There is the inconvenience from smoke and danger from fire. The boiler is extravagant in fuel, and the engines

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cannot be used with an early cut-off owing to the necessity of reversing them so often, and being able to stop and start at any part of the stroke with the full load on.

These disadvantages disappear in a great measure by the use of the electric derrick-crane.

One of these has been at work at some extensive alterations at Alnwick Castle, the seat of the Duke of Northumberland, for some months with the greatest satisfaction.

In endeavouring to introduce electric derrick-cranes, we are, of course, met with the objection that a generating plant is necessary—same as for the travelling cranes already mentioned.

In this particular instance, however, the ordinary lighting plant of the Castle is used, and this is driven by water-power, consequently supplied at a small cost.

Worm gearing is used between the crane and motor, and the same arrangement of frictional bevel gear is used for reversing as for the travelling cranes. The various movements are under perfect control.

The author has designed and constructed an electric derrick-crane for contractors' use. It has a steel jib 75 feet in length, giving a sweep of 120 feet from one side to the other. The arrangement of the gearing for raising the load, raising and lowering the jib, and turning the crane are very similar to that adopted in steam-cranes.

It has been thought advisable in this crane to make the motor reversible, as it would not be considered safe to lower the jib with a brake; when this is being done, therefore, it is under the control of the motor. The motor is a two pole machine.

The armature is 10 inches in diameter and 7 inches long, and at 1200 revolutions will develop 6 horse-power continuously, and may be overloaded intermittently to 25 per cent. or 30 per cent.

The winding is arranged in compound, the shunt circuit being controlled by a separate switch, so that when the motor is stopped the shunt circuit is still closed. This arrangement insures starting without an undue expenditure of current. The reversing is effected by the movement of

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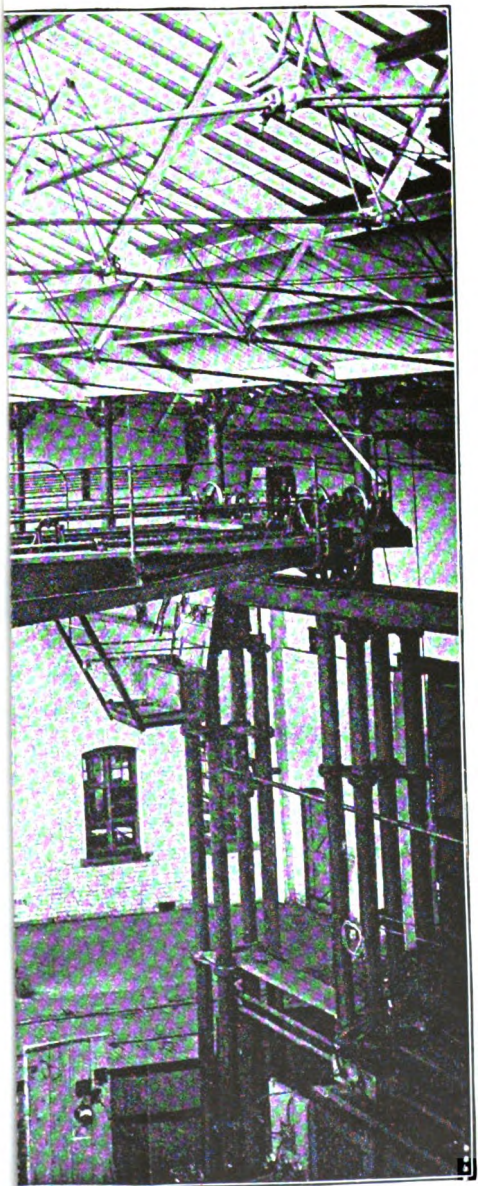

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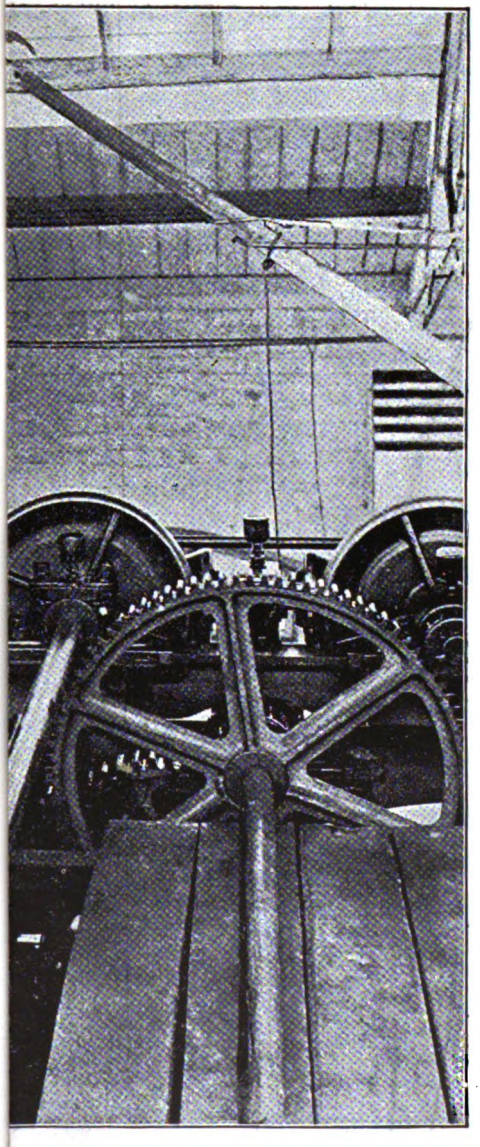

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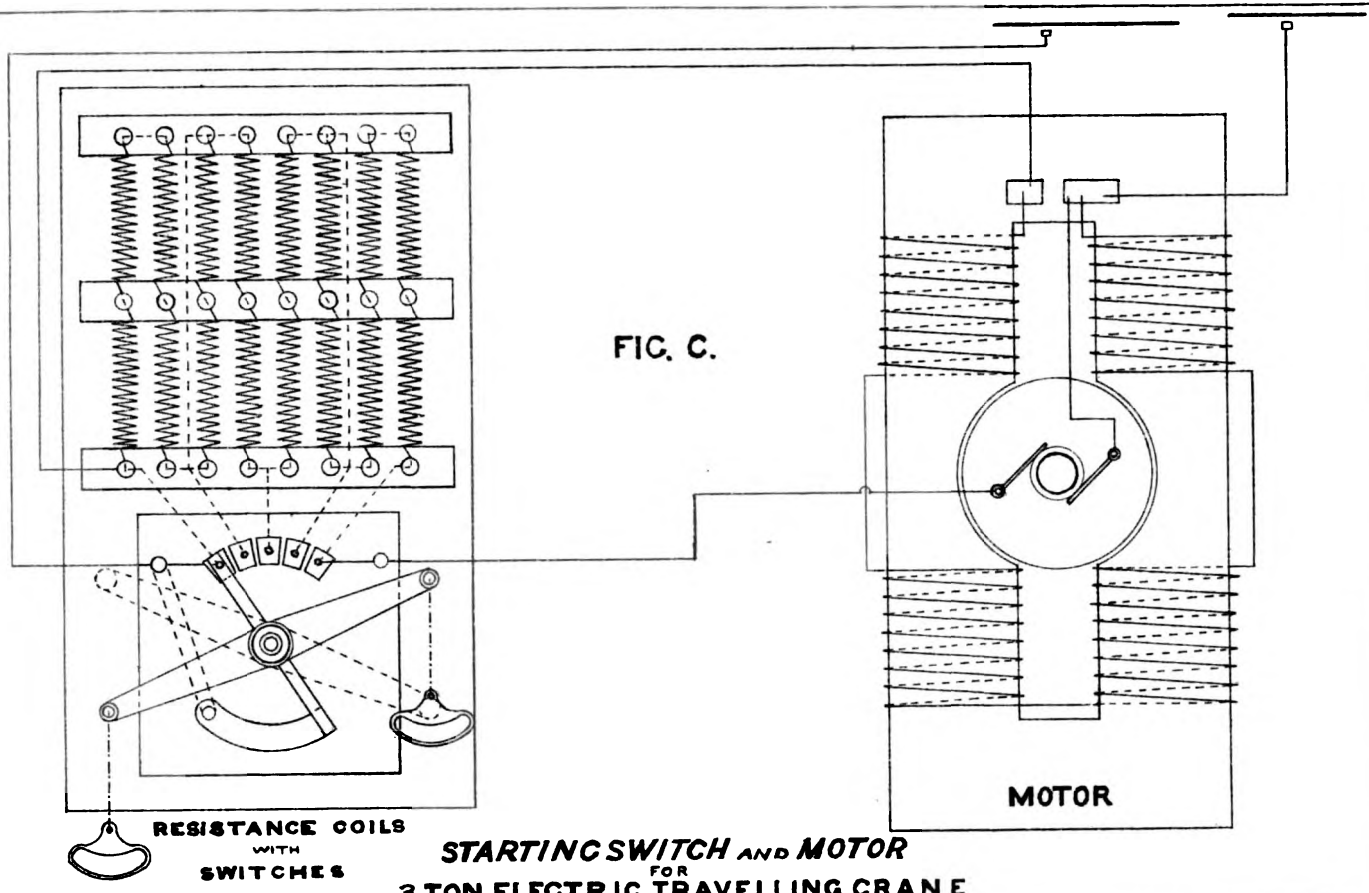

Fig. C.

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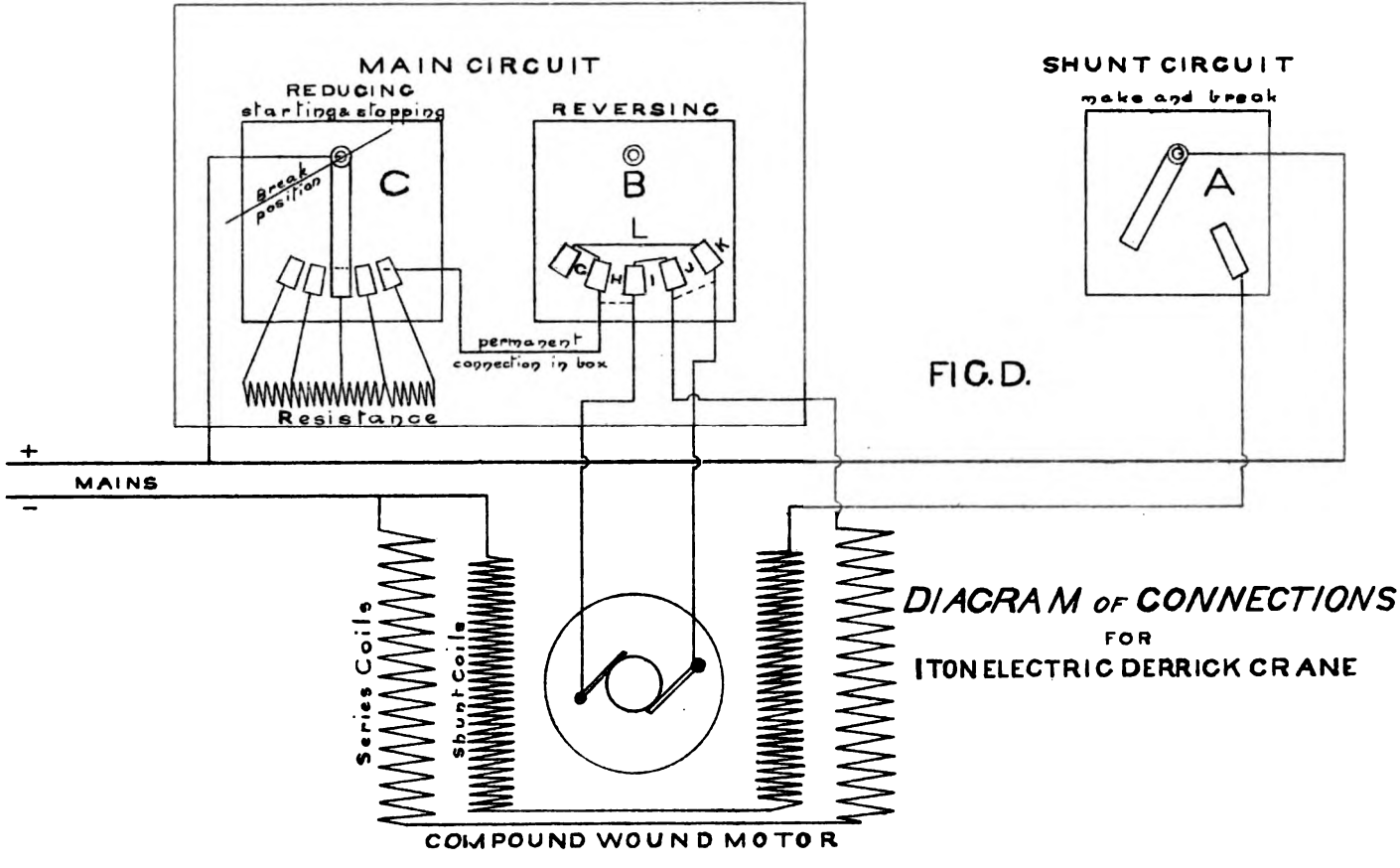

FIG. D.

DIAGRAM OF CONNECTIONS
FOR
1 TON ELECTRIC DERRICK CRANE

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the switches as shown on diagram D, and is under as perfect command of the driver as a steam-engine.

When required to start the motor, the shunt switch is first closed, exciting the field of the motor, the armature remaining at rest. The reversing switch B is now put for running backwards and forwards, and the make and brake switch C now completing the armature circuit through the resistance.

When the lever is on block D all resistance is out, and the motor running at maximum speed.

If it is required to reverse the motor, the circuit is broken at C before the switch B can be moved at all. This locking is accomplished by frame E being moved backwards and forwards by cam F, the reversing lever is now thrown over and the circuit made again by C.

The shunt switch remains on all the time, only being broken when crane is not required for a length of time. The coupling up of the reversing switch is shown, G and H, I and J, being coupled together, or H and I, J and K; L is a permanent connection.

This operation causes the current to flow in different directions through the armature, while the field current is always in one direction.

The motor is carried by a strong bracket on the mast of the crane, it makes 1200 revolutions per minute, and drives a counter shaft by means of helical gearing. It is constructed on Immisch patents by the General Electric Power and Traction Co. of London.

The current for working this crane is to be supplied from an existing lighting plant.

The first cost of an electric-crane with motor complete, but exclusive of generating plant, is somewhat less than a steam-crane of similar power.

In a large contract, where several cranes are in use, the saving in having electric-cranes worked from a central station would be very great indeed; and now that a short time will see the streets in our principal towns laid with cables, the builder of the near future has only to arrange with the supply company to tap the wires and put up his electric-

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crane, instead of using the wasteful, unsightly, and smoky steam-crane of the present.

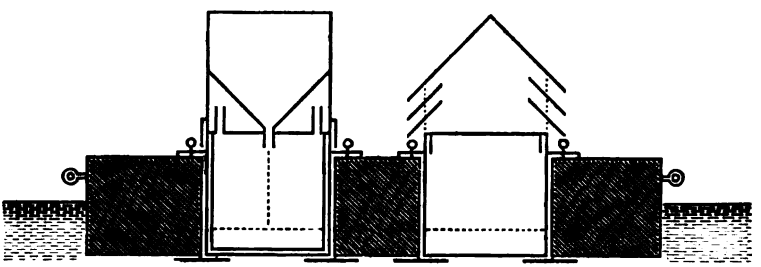
There are several other forms of hoisting machinery to which electromotors are applied with great economy, and the system is becoming a serious rival to hydraulic transmission. The Southampton Dock Board have decided to work all the cranes on a recent extension by this method.

On a Floating Rain-Gauge and Evaporator. By Dr W. G. Black, F.R.M.S. Edinburgh.*

It has been considered a matter of uncertainty what differences, if any, might exist between observations on the amounts of rainfall and evaporation of water, on land and on water respectively.

With the object of investigating such phenomena this double instrument has been constructed, having a rain-gauge and evaporator fixed on a raft exposed on the surface of water away from land.

The rain-gauge is 6 inches in diameter and 12 inches in height, and is divided into a collector and a receiver, separated



by a diaphragm. The water found in the flagon is measured in inches.

The evaporator is also of 6 inches diameter and 6 inches high, and is filled with 1 to 2 inches of water. It is covered over by a louvre 6 inches high to keep out the rain and

* Read before the Society, 11th April 1892.

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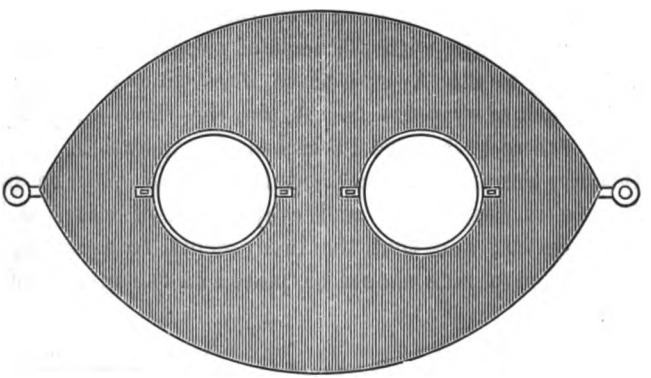
birds, but to admit of free diffusion of vapour and passage of wind.

The raft was taken out every day or two by boat to a mooring buoy, and brought back the following day. The amount of rain and evaporation was measured, and the temperature of the water and of the air taken at the same time.

From these data, and from those taken in the town at the same time, it was found that more rain fell on the land, and less evaporation took place there than on the lake during the same period. The actual figures being 3·92 inches on the lake as against 5·10 inches in the town, and 2·21 inches on the lake against 1·24 inches in the town.

The water averaged 2° warmer than the surrounding air on land with one exception. The maximum temperature was 67°, the minimum 54°, and the mean 58·7° F.



The maximum temperature of the air on land was 65°, and the minimum 53°, with 57·4° as a mean.

The average daily evaporation on the water for the month was only 0·06 inch, a small amount for summer, which would give an estimate of 14·55 inches per annum.

The wind during the month was from the west for eight days, and for eighteen days from the N.W. The wind was more prevalent over the lake than over the land, and would therefore occasion a relatively increased evaporation.

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The cause of there being less rain on the lake than in town may have been due to the N.W. winds blowing the showers on to the slopes of the hills to the windward, and to the plantations in the neighbourhood sheltering it to leeward, probably also the cause of there being more evaporation on the lake than in the town was due to the surface of the water being more exposed to the sun wind than the site in the garden area, attached to a dwelling surrounded by houses, and so in the shade for the most of the day, and sheltered from horizontal breezes.

During the period of thirty-two days there were eighteen wet or showery days, and fourteen dry days, or about five to three, which shows a large proportion of wet days for that part of the season, which had been in the earlier part drier than usual. There does not appear to be a strict relation between the amount of evaporation and the number of dry days, as evaporation may be hastened by gales and winds in stormy weather. Thus, from 29th July to 2nd August there were four dry days, with ·36 inch of evaporation; but from 2nd August to 6th August there were three showery days, with ·40 inch of evaporation. Again, the three rainy days of August, 7th to 10th, gave 1·3 inches of evaporation.

It may, therefore, be inferred that there may be much difference in the rainfall and evaporation of water on land and on water; and that the instruments to ascertain the proportion on a lake should be placed on the surface of the water.

The Concentration of Ores, introducing a New Dry Centrifugal Concentrator. By RICHARD STANFIELD, F.R.S.E., Assoc. M.Inst. C.E., A.R.S.M., Professor of Engineering, Heriot-Watt College, Edinburgh.* (With Four Plates.)

Mining and the necessary processes for the extraction of the valuable from the useless portion of ores will always be

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* Read before the Society, 11th April 1892.

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subjects of interest to the community at large. Mining shares are not always a profitable investment, although the speculating public is very ready to put its money into companies which, as a rule, show splendid returns (on paper). A very large amount of money has been lost in these undertakings, and in many cases, mines, which really contained a rich and valuable ore, have been abandoned owing to the want of proper machinery to treat the mineral.

Every day new fields for mining operations are being opened up in all parts of the world. The recent gold mining operations in North Wales have taken many people by surprise, although gold was extracted in Great Britain years ago. The gold generally occurs in this country in such small quantities as scarcely to pay for extraction by the ordinary processes, though there is little room to doubt that a more promising outlook is before the British gold-miner by the adoption of the dry concentrating machinery described in the latter part of this paper.

Metalliferous minerals and metals (which rarely occur native except gold) are always associated with, and in most cases intimately mixed with, large quantities of gangue, that is, earthy matter.

The proportion of valuable mineral in an ore is generally very small, take for instance, gold, which may vary from 3 pennyweights to 3 ounces per ton of ore, sometimes a richer sample may be obtained, but, as a rule, 1 ounce of gold per ton of ore is considered good. The less valuable minerals occur in larger proportion, but always mixed with a large amount of useless veinstuff or gangue.

It is therefore evident that it would be a very expensive and wasteful proceeding to attempt at once to directly extract such a small quantity of the mineral from so large a bulk of earthy matter, it is here that concentration is necessary.

There are two methods adopted in the treatment of ores for the extraction of their valuable constituents, viz.—the *wet method* in which water is the principal agent, and the *dry method*, in the latter water is unnecessary, and in general prejudicial.

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The principal processes in the mechanical treatment of ores by each of the above methods are as follows:—

1. Crushing or pulverising.
2. Classifying the crushed ore according to the size of particles.
3. Concentrating or separating the valuable portion of each size, obtained in the classifying process, from the useless portion.

Crushing.—The metalliferous minerals containing gold, silver, lead, zinc, tin, &c. (all, except gold, occurring in chemical combination with other elements), are always mixed with a veinstuff which may consist of such minerals as quartz, various forms of calcspar, dolomite, fluorspar, &c. This mixture, generally composed of fine particles intimately blended together, sometimes, though rarely, of coarse fragments, requires to be broken up in order to separate the useful particles from one another and remove the waste.

The ore when brought from the mine is broken up into small pieces, suitable for further reduction, in an ordinary stone-breaker, generally of the "Blake" type. The more or less coarsely crushed ore is then subjected to further pulverisation in "stamps," "rolls," or other types of crushers.

These "stamps," of which there are numerous varieties, usually consist of heavy iron blocks, weighing from 500 to 900 lbs, fixed at the extremities of vertically moving rods. The rods are lifted by cams or other suitable means, and then allowed to fall through a height of about 8 inches on to the lumps of ore until the ore is reduced to the required degree of fineness.

The "stamps" are usually worked *wet*, though they are sometimes used for *dry* crushing.

Of late years "rolls" have been largely adopted for pulverising ores, and recent experience seems to show that for economy of working and reliable results the roller system of crushing is to be preferred. In these machines the crushing is effected by and between the surfaces of revolving cylinders. Of the many different varieties of "rolls" at present in use, the "Krom" principle seems to give the most satisfactory results.

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The Krom "rolls" are essentially *dry* crushers, and consist of two horizontal cylinders or rolls, both of which are driven by belt-gearing. One of the rolls is mounted in a swinging pillow-block, and kept in contact with the second roll by means of powerful springs.

The other types of crushers, of which there are a great variety, are used to a certain extent, but are not of sufficient importance to render it necessary to give a detailed description in this paper.

If the minerals are very intimately mixed together, the ore should be crushed very fine, as there is then a better chance of getting rid of most of the waste matter, which otherwise would remain attached to the lumps of mineral. With fine stuff, however, the mechanical process of separation in most machines is rendered very difficult, and there is the probability of the finer and sometimes the richer portions of the ore being lost.

Classification.—No matter what method of concentration is adopted, a preliminary classification or gradation according to size is absolutely necessary, and the more complete the classification the more perfect will be the after concentration.

A first or coarse classification may be obtained by passing the crushed ore through a series of revolving screens or trommels. These consist of cylindrical or slightly conical frames covered with wire-gauze of varying degrees of fineness, and mounted on axes which are driven by suitable gearing, the axes are generally slightly inclined to assist the passage of the unclassified ore through the screens.

The screens may be arranged in an inclined frame so that the particles of ore dropping through the meshes of one screen can pass into the next, and so on, the largest particles being retained in the upper screens, the finest passing to the bottom.

Sometimes the above procedure is reversed and the finest meshed screen is at the commencement of the series, in this case the smallest particles of ore, &c., pass through the meshes of the first screen. The remainder traverses the screen and passes into a shoot at the end, and is conducted into the next screen in the series where the next finest sample is separated.

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In an ingenious wet classifier (Fig. 2, Plate IV.), as used at Frongoch in Wales, the ore is fed down a launder L into the interior of a cone C placed inside a second cone A in connection with a lower chamber D, from which water is forced. The lighter particles are carried upwards by the force of the current and pass down a launder K, whilst the heavier particles fall to the bottom of the chamber D, from which they can be removed from time to time through a valve F.

In a machine (Plate I.) invented by Mr Thomas Clarkson, London, for classifying the crushed ore according to the size of the particles, a series of horizontal screens A are arranged, one above the other, and mounted in a main frame. They are made to receive a sort of reciprocating motion or shake, which causes the ore to move along the screens, thus insuring the effectual action of each screen. The material as it passes through each screen is received on platforms D underneath, along which it is propelled by means of travelling brushes C until it falls on to the screen next below. The same brushes also sweep the under parts of the screens to prevent clogging. The length of time during which the ore is permitted to remain on each screen can be regulated with great accuracy by suitably adjusting the operating mechanism. This classifier is capable of grading the ore into six different sizes, ranging from particles which will be retained by a 40-mesh sieve to those passing through an 120-mesh. The pipe E is connected to an exhaust fan producing a powerful down draught which increases the output of the machine. This machine works very efficiently, and the grading of the particles of crushed ore is practically perfect. Each grade of ore, after it has traversed the screen, passes down shoots B at the end of each tray. This machine will classify from 40 to 50 tons per 24 hours.

Concentration.—In the process of concentration advantage is taken of the different specific gravities of the minerals and associated earthy matter from which they are to be separated.

The majority of processes at present in use are wet ones, and depend upon the varying rates with which bodies of different specific gravities will sink in water.

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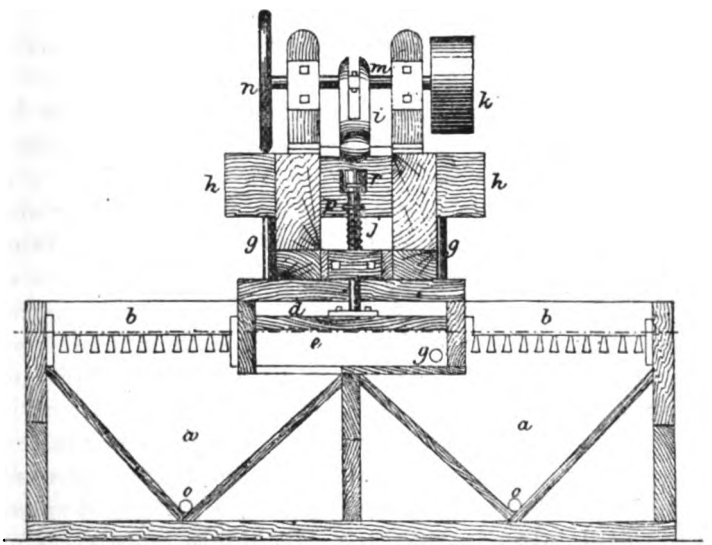
It will be seen from the following table of the specific gravities of a few of the most important metals, minerals, rocks, &c., that there is, as a general rule, a fairly wide margin between the specific gravities of the minerals and their associated gangues:—

	Specific Gravity.
Gold (variation due to the metals it may be alloyed with),	12 to 20
Silver (native),	10·1 „ 11·1
Argentite (sulphuret of silver),	7·19 „ 7·36
Galena (lead sulphide),	7·2 „ 7·77
Cassiterite (oxide of tin),	6·4 „ 7·1
Blende (sulphide of zinc),	3·9 „ 4·2
Fluorspar (fluoride of calcium),	3·0 „ 3·25
Calcite (carbonate of lime),	2·6 „ 3·0
Quartz (silica),	2·5 „ 2·7
Gypsum (sulphate of lime),	2·2 „ 2·4

The wet processes of concentration may be conducted in two general ways:—In "Jigs" or "Hutches," or on "Tables."

In the "Jigging" process the ore to be treated is fed into a frame with a gauze-sieve or perforated plate bottom. The



frame is placed inside a box or hutch, and the ore is subjected to a series of jerks or lifts in rapid succession from a column of water forced through the perforations. The light particles

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are lifted up to the top and carried away by the water at the overflow. In working the "Jig," either the sieve is jerked up and down in a cistern of water, as in the "Hand Jig," or the water is forced up through the sieve by means of a piston, in the latter case the sieve is fixed.

In "Collom's" Jig, shown above in vertical section, the ore is fed on to screens *b*, where it is subjected to the action of uprising currents of water. The main water-supply is connected to rectangular chambers *e* (one only is shown in the fig.), which are provided with pistons *d*, and communicate with spaces *a* underneath the screens. Motion is given to the pistons by means of a rocking tappet-lever *i*, which is operated by means of a crank and connecting-rod from a shaft *m*.

The water is thus forced upwards through the screens in "jerks," and the lighter portion of the ore, that is, mainly the gangue, is washed away over the sides of the screens. The concentrates are removed from time to time off the screens, and any fine metalliferous portion of the ore that may pass through the meshes of the screens is received in the compartments *a*. This machine is not continuous in its action, as it must stop each time that the concentrates are removed.

With regard to the "Table" concentrators, these may be divided into two groups—(1), with stationary or fixed tables; (2), with moving tables.

In the stationary table concentrators the crushed ore and water is allowed to flow over tables or shallow troughs of varying width, the narrowest being at the commencement of the flow, consequently the velocity of the current is greatest at this point, and the heaviest particles settle at this stage. The width of the tables is gradually increased, the velocity of flow being correspondingly diminished and the finest stuff is deposited at the tail end of the tables, the gangue or earthy matter being carried away by the water. These tables are often of great length and require a large quantity of water. When used in connection with gold-mining, cross-pieces of wood called "riffles" are inserted in the tables, mercury being placed at these points to catch up the gold and form an amalgam.

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In the second group, the tables may receive a slight swinging motion in the direction of the flow of water, or they may be what are termed "Percussion Tables." In the latter the table is subjected to a sharp blow either at right angles to the direction of flow as in the "Rittinger" table, or in the direction of flow as in "Halley's" percussion table.

In the "Rittinger" machine shown in plan and elevation in Plate III., the table is divided down the centre so as to form two separate tables A_1, A_2, the entire table is suspended by four rods or chains at the corners, and is moved sideways by means of a series of cams, K, fixed on a roller R. When released from a cam the table is returned by a spring, N, and strikes against a fixed block M. The ore and water is fed on at one corner from the dividing planes T_1, the other planes T_2 distributing cleaning water, the strongest flow being furthest away from the ore plane T_1. The particles of ore, &c., have two movements, one down the plane, due to the flow of water and inclination of table, and the other across the table, caused by the percussion, the result is a diagonal movement downwards. The heavier particles are thrown farther by the blow, and, owing to their greater weight, there is greater friction between them and the table than the lighter particles, consequently they are longer and more exposed to the forward movement than the latter in the same interval of time. They thus tend to travel outside the lighter particles, and gradually separate, according to their specific gravities, into bands, the separation being more perfect the nearer the edge of the table where the different grades of quality of ore are delivered into separate launders. The velocity of the stroke requires to be adjusted according to the size and character of the ore treated, varying from 1 foot per second for coarse stuff to ·5 feet per second for fine. The flow of water is regulated so as to assist the separating action. The output of six double tables is from 10 to 12½ tons per 24 hours. The inclination of the tables may be adjusted to suit the character of the ore being treated.

In the later types of wet concentrating machines, as in the "Frue Vanner" shown below, the ore in a fine state of division, together with a quantity of water, is fed on by a

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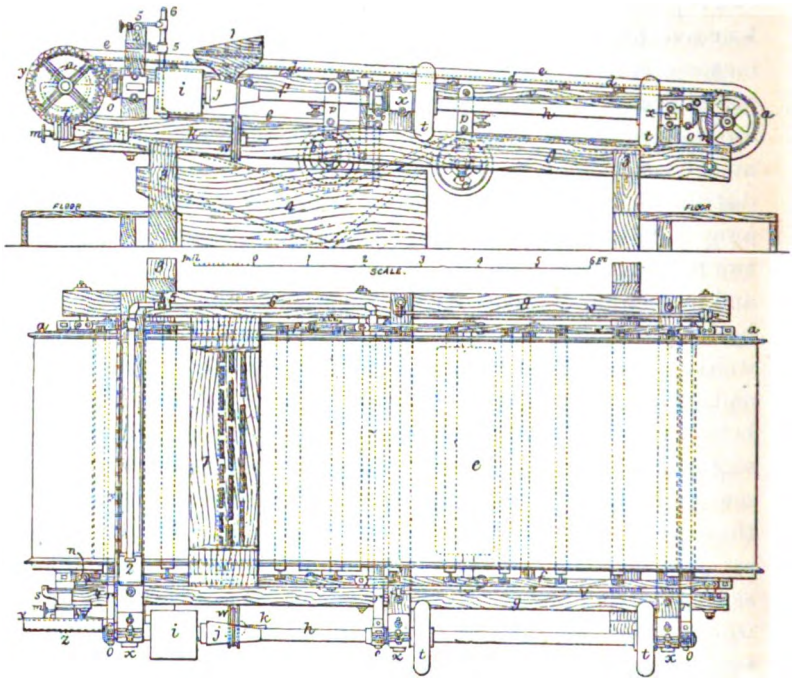
spreader, 1, near the top of an inclined travelling band *e*, which has an uphill movement, clean water being run on at the same time from a pipe, 2. The band is mounted in a frame which is subjected to a side shake; the amount of shake, travel, and inclination of band are so adjusted that most of the earthy matter is washed down the band, while the metalliferous portion is carried onwards and finally deposited in a tank of water, 4, through which the band is



made to pass, underneath the table. The depth of ore on the table is about half an inch, some of finer metallic particles are washed down with the waste, and are collected in settling tanks. These deposits are known as "slimes," and are sometimes very rich in mineral. So far it has been almost impossible to extract the valuable portion of these slimes, owing to the difficulty of getting rid of the earthy matter without losing the mineral.

In other machines of the "Frue Vanner" type, the main difference seems to be in the character of the shake given to

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the table. These machines are continuous in their action, and are considered to be the best wet concentrators, one machine will probably turn out 6 to 7 tons of concentrates per 24 hours.

Concentration by Dry Method.—It is a well-known fact that in some of the finest mining districts in the world, notably in Australia and Africa, there is a great scarcity of water during the whole or some portion of the year, consequently the concentrators previously described, which are dependent for their successful operation on a good and abundant water supply, are of little value. Assuming, however, that a good water supply exists, concentration by the wet method is not altogether satisfactory. The output, for instance, of a "Frue Vanner" type of concentrator is only about 6 tons per 24 hours, and even at that the degree of concentration is far from being perfect, at the same time the finer and often richer particles of the ore are apt to float on the water and be carried away. This is especially noticeable in gold mining, where there is great loss by reason of the difficulty in retaining the finest particles of the metal or "float-gold."

Many attempts have been made to produce an efficient dry concentrator, by causing a current of air to act upon the ore when falling in a thin stream across the direction of the current which carries away the lighter particles. In another machine the air current acts upon a thin layer of the ore when moving over a tray of shot which is agitated, the heavier particles sinking below the shot out of the action of the air current, the finer particles being aspirated off. In both of these methods, the separation has been very ineffectual, on account of the difficulty in obtaining a current of air of uniform velocity throughout. The unreliable results obtained from such machines have caused dry concentration to be somewhat discredited by mining experts.

The author and his co-inventor, Mr Thomas Clarkson, had their attention directed a few years ago to the importance of dry concentration, and from a careful examination of the dry concentrators invented up to that period, also from numerous experiments, were led to the conclusion that the main

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principle of the machines then in vogue (the "blowing method") was at fault.

As a result of their labours the "Clarkson-Stanfield" Centrifugal Concentrator (Plate II.) has been placed before the mining world.

The "Concentrator" consists essentially of a vessel D capable of rotating about a vertical axis, and a fixed receiver, which is divided into a number of concentric compartments, C_1, C_2, &c. The rotating vessel D is termed a "distributor," and is provided at its periphery with a series of orifices, in the machine shown in the drawing the orifices are at the extremities of grooves which lie on the surface of a cone whose generating line makes an angle of 45° with the axis. The classified ore is fed from a hopper H into the distributor, and the particles of ore are projected from its periphery with uniform angular velocity.

The particles being approximately of the same size, those of lower specific gravity are sooner overcome by the resistances of the atmosphere and gravitation, fall short, and are collected in a compartment of the receiver near to the centre, while those of a higher specific gravity are thrown further, and fall into a separate compartment more remote from the centre.

The operation of the "Concentrator" is based upon the principle that when a particle of weight W is revolved with a velocity V around a vertical axis and at a distance R from it (G representing the acceleration due to gravity), the centrifugal force is represented by the expression

$$\frac{WV^2}{GR}$$

Now in this expression for any one place G is a constant quantity, R, the outside radius of the distributor is also constant, V, the velocity with which the outer edge of the distributor revolves is also made constant, and therefore W, the weight of the particle, is the only variable quantity. Therefore the centrifugal force with which each particle is ejected is proportional to its weight, and when the particles are all of the same size the weights are proportional to the densities. A particle having been ejected has a kinetic

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energy (or energy of motion) proportional to the force with which it has been ejected and consequently to its weight, as shown above, or to its density for particles of equal size.

The resistance of the air impedes the motion of each particle to an extent measured by the ratio of this resistance to the energy of the particle, and thus causes a separation of the particles.

Take, for instance, particles of Galena and Quartz of equal size, the specific gravities being 7·5 and 2·6 respectively, therefore the kinetic energies of the particles are in the ratio of 7·5 to 2·6 or 2·88 to 1, consequently for same size particles the Galena will be projected 2·88 times the distance of the Quartz.

It is evident that we have here a machine which will effectually separate minerals whose specific gravities differ only by a very small amount. From an inspection of the table of specific gravities, previously quoted, it will be seen that there is a wide available margin between each mineral, consequently there should be no difficulty in obtaining a perfect separation or concentration. Numerous experiments have proved this beyond question.

The centre compartment C_6 of the receiver is in connection with a centrifugal fan F, which causes a slight inward current of air to further assist the process of separation, and also draws away the light waste particles. The fan discharges into a suitable dust chamber or into the air. It should be noticed that the strength of the air current is much greater near the centre of the receiver than at the outer portions, consequently the lighter particles are acted upon to a greater extent than the heavier ones, and this is one of the objects in view.

Each Concentrator is provided with a bin divided into six compartments according to the different grades of ore. A valve at the bottom permits the ore to pass through the hopper H into the distributor, thence into the receiver, from which it is swept as concentrates and tailings, by brushes B, into shoots leading to wherever may be convenient. The brushes are fixed to arms A, suitable gearing is provided

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whereby the arms and brushes are caused to move round the receiver.

The different grades of ore require a slight alteration in speed, and for this purpose an efficient speed regulator is attached to the machine, and by it the speed can be adjusted to the fraction of a revolution without stopping the machine.

It is essential for the efficient working of the above machine that the ores for concentration shall be dry enough to readily pass through a hand sieve of the required fineness. In most mines the ore, especially tailings, is dry enough, but if it is desired to treat wet ores or tailings, a simple drying machine is used as shown in Plate III.

The *drying machine* consists of a rectangular chamber made of wrought iron plates and containing three revolving tables T, fixed to a vertical shaft, a furnace F is placed at the lower part of the chamber, and the hot gases are made to impinge upon the wet ores, &c., on the tables. The wet ores or tailings are fed in through a hopper, H, and falling upon the first table near the centre are turned over and over, so as to expose fresh surfaces to the hot gases, by a series of inclined scrapers S. The scrapers tend to force the material towards the edge of the table from whence they drop to the next. The second table is provided with rollers R which break up any lumps that may occur in the ore, in this case the scrapers force the particles to the centre of the table so that they may pass through a central opening, C, on to the last table. The drying is completed on the third table, and the dry ore, &c., then passes away by a shoot, L, to an elevator, thence to the "Classifier," and afterwards to the "Concentrator." The speed of the tables may be regulated to suit the condition of dryness of the ore, &c.

A complete arrangement of plant for treating an ore by the dry method is shown in Fig. 1, Plate IV. The ore is first roughly broken in an ordinary stone-breaker, it is then elevated and passed through a "grizzley" (a kind of coarse riddle). There will be some ore at this stage fine enough to pass through a 40-mesh sieve, this is led directly to the "Classifier." The remainder goes to a second stone-breaker and afterwards to the pulveriser, in this case a set of Krom's rolls. The pul-

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verised ore is then classified and elevated to the Concentrator. Fans are placed at various stages of the process for taking away the fine dust, which generally contains little or no mineral. A cyclone dust-extractor is also introduced, and is found to be of great assistance in removing any objectionable dust left by the fans.

The concentrates, as obtained from these machines, remain to be treated by smelting, chlorination, cyanide, or any other suitable process.

The total weight of Classifier and Concentrator, to treat about 40 tons per 24 hours, is under 3½ tons, and one skilled man can supervise at least five machines. Taking the cost of labour at 1s. per hour and coal at 30s. per ton, it has been estimated that classification and concentration can be done by these machines for 1s. 4d. per ton of ore treated. This is considerably under the cost of wet treatment, and when we consider that a machine as described, occupying less space and requiring less power than a wet concentrator, can concentrate far more efficiently about seven times the quantity of ore, it is evident that mining industries should receive a great impetus by the introduction of these dry concentrators.

One of the great openings for this Concentrator is for the treatment of tailings or waste from the old wet processes. Such tailings generally contain a few pennyweights of gold to the ton, too small an amount to render extraction profitable by any former process, these can be concentrated until the resulting concentrates have many ounces of gold per ton.

Sometimes gold occurs in an ore associated with refractory compounds of sulphur, arsenic, iron, copper, &c., which prevent the saving of the gold by the amalgamation treatment, and the amount of gold is too small to render chemical treatment profitable. By concentrating say 100 tons of such an ore we should obtain say 5 tons of material containing all the metallic portion of the ore and ready for immediate treatment by any of the known chemical processes of gold extraction.

There is no doubt that eventually dry crushing and concentration with some chemical extraction process will supersede the costly and inefficient amalgamation method still largely in operation.

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The "Concentrator" is also admirably suited for grading according to size, such homogeneous substances as cement, emery, blacklead, ground glass, porcelain, &c.

Results of an experiment with a sample of gold ore taken from the mine at Carn Dochan in North Wales:—

Weight of ore taken, . .	500 lbs.	
Classified.		
Between 40 and 50 mesh, . .	70 lbs.	Concentrated.
„ 50 „ 60 „ . .	72 „	
„ 60 „ 70 „ . .	46 „	
„ 70 „ 90 „ . .	28 „	
„ 90 „ 120 „ . .	39 „	
Through 120 „ . .	30¼ „	
Cyclone dust-extractor and stuff in pipes, . .	185½ „	Assay—Nil.

After Concentration.

Weights.

·5 per cent. 1st class concentrates, . 55 per cent. lead.
6·0 „ 2nd „ „ .
93·5 „ Tailings from concentrator.

These concentrates and tailings gave the following results on assay:—

1st Class concentrates, . .	21 oz. 5 dwts. 8 grs.,	fine gold per ton.
	31 „ 4 „ 21 „	„ silver „
2nd „ „ . .	1 „ 2 „ 20 „	„ gold „
	4 „ 9 „ 12 „	„ silver „
Tailings from concentrator, .	0 „ 1 „ 7 „	„ gold „
	0 „ 0 „ 8 „	„ silver „

Average value of tailings from concentration and dust from classification was 16 grains of fine gold per ton.

The above results show that practically all the precious metals are saved in about 2·5 pounds of material.

Results of an experiment with British Broken Hill ore for the separation of Galena from Blende:—

Assay of grades from the concentration of 70 *to* 90 *mesh stuff.*

1st compartment (outer),	84 per cent. lead,	3 per cent. zinc.
2nd „ . .	76 „ „	9 „ „
3rd „ . .	44 „ „	27 „ „
4th „ . .	9 „ „	38 „ „
5th „ . .	1·8 „ „	25 „ „
6th „ . .	1·1 „ „	20 „ „

Nos. 1 and 2 could be mixed together.
„ 3 re-treated.
„ 4, 5, and 6 mixed together.

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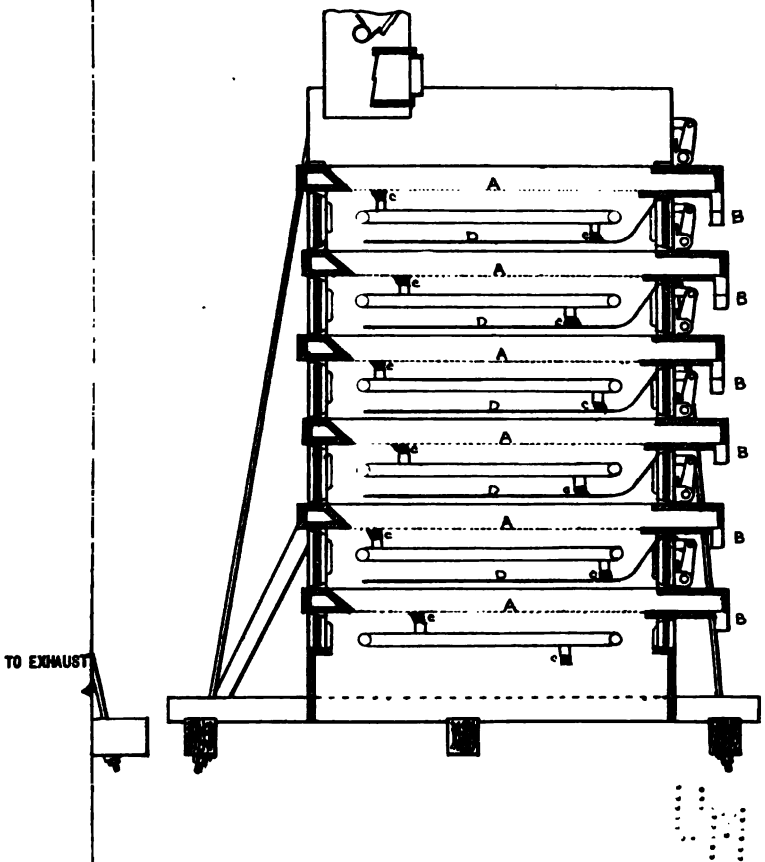

CLASSIFIER.

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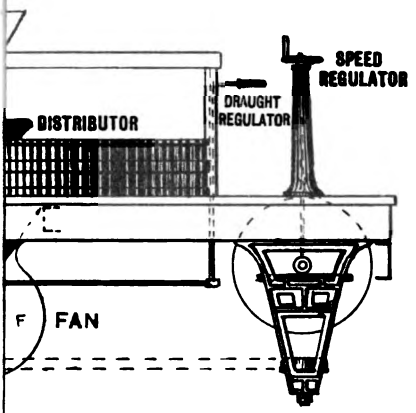
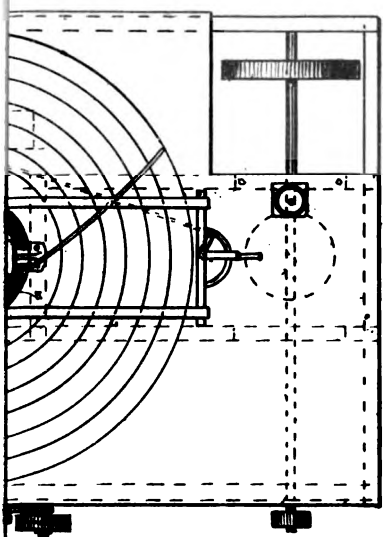


ENTRATOR.



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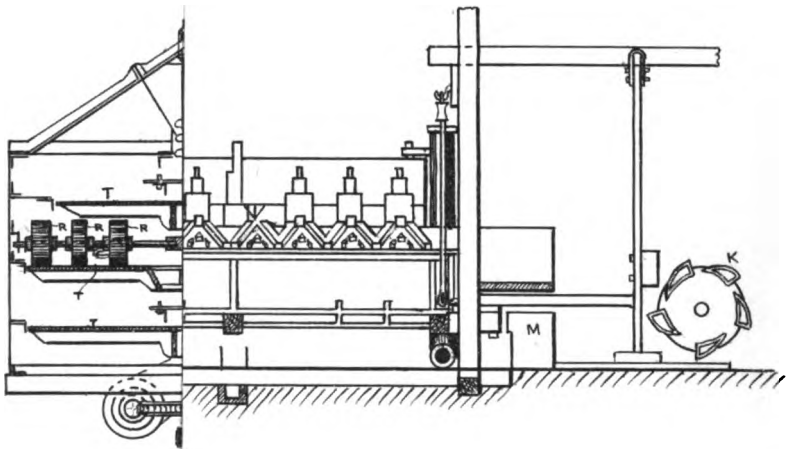

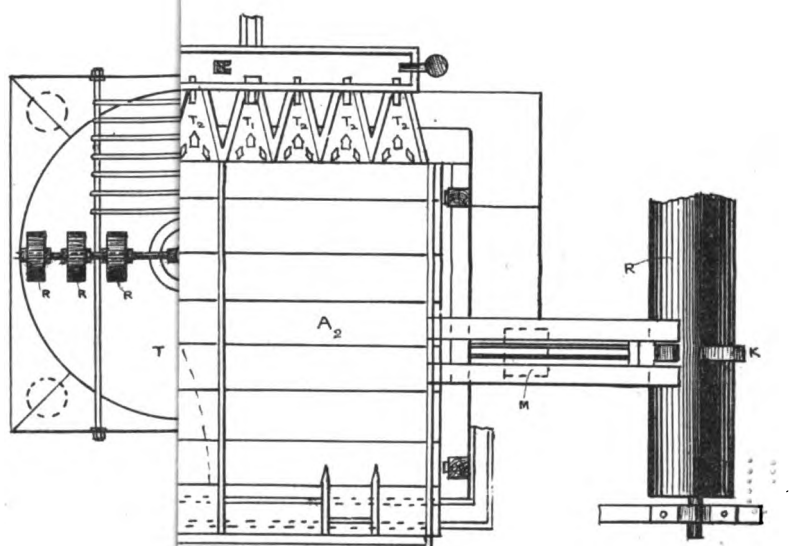

NGER'S TABLE."

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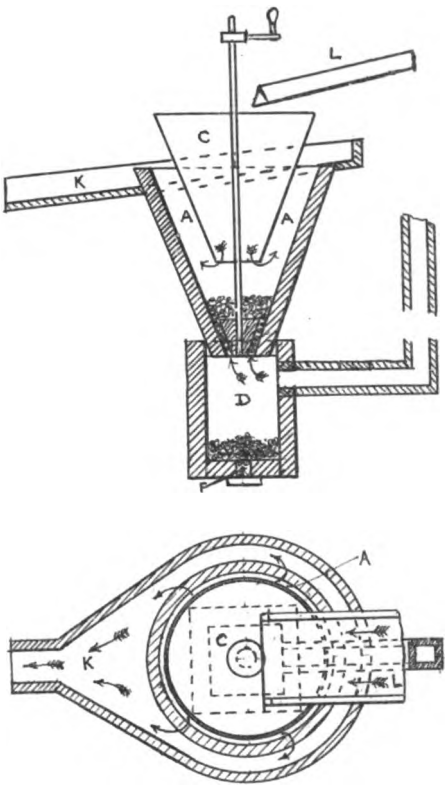
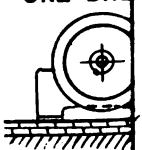


FIG. 2.
FRONGOCH CLASSIFIER.



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This would bring the impurity in each case below the smelter's limit of 6 per cent., and would give a very good percentage of lead. The relative weights of the above grades were as follows:—

1st grade, . .	9 lbs.	4th grade, . .	11½ lbs.
2nd „ . .	6 „	5th „ . .	12 „
3rd „ . .	7½ „	6th „ . .	15 „

Results of the concentration of another Welsh gold ore:—

Concentrates 1st = 8 per cent., 4 oz. 6 dwts. fine gold per ton.
„ 2nd = 14 „ 0 „ 3 „ „ „
„ 3rd NIL.

Below is a series of experiments with a South African gold ore from the Laydenberg district, the original ore contained about 1¼ ounces of gold per ton, of which about 7 to 8 dwts. were saved by the amalgamated plates. The gold was supposed to be in a very fine condition, and consequently most of it was lost in the wet process used. The original ore was classified and an assay made of each grade with the following results:—

	Weights.	Assay, per ton.
No. 1. Over 40 mesh, . .	5 lbs.	...
„ 2. 40– 50 „ . .	22½ „	16 dwts.
„ 3. 50– 60 „ . .	27 „	17 „
„ 4. 60– 70 „ . .	10¼ „	17 „
„ 5. 70– 90 „ . .	3 „	1 oz. 0 „
„ 6. 90–120 „ . .	8½ „	1 „ 6 „
„ 7. Through 120 coarse,	27 „	2 „ 4 „
„ 8. „ 120 fine, .	9½ „	2 „ 8 „

These results are remarkable as proving that the gold was present in an exceedingly fine condition, it was calculated that 67 per cent. of the gold was contained in ore passing through a screen $120 \times 120 = 14{,}400$ holes per square inch. This fine stuff is about 32 per cent. of the whole. Of the remaining 33 per cent. of the gold, about 50 per cent. was caught by the concentrator, thus altogether about 83 per cent. of the gold was saved, and this in so fine a state that it needs little speculation as to what would become of it in a wet process.

All the above experiments and tests were conducted on a full size machine, and the assays carefully conducted in most cases by an independent assayer.

The author desires to convey his thanks to Messrs E. & F.

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N. Spon, who kindly lent the blocks illustrating the earlier processes of concentration and classification. These illustrations were taken from Mr C. G. Warnford Lock's book on 'Mining and Ore Dressing Machinery."

On the Practical Application of Heat to Domestic Cooking and Boiler Arrangements. By Wm. Gray, 52 Frederick Street, Edinburgh.* (With Two Plates.)

I propose in this paper giving some views of the advantages and disadvantages of the different modes of distributing heat, either in heating water or for cooking apparatus of the various kinds now used in domestic dwellings, hotels, clubs, restaurants, etc., by the construction of the various kinds of flues for the economy of fuel.

There can be no doubt that of all powers in nature, as well as of art, it is one of the most valuable powers which have been placed within our reach, that of producing and distributing heat. Destitute of this power, the condition of man in the world would not be superior to that of the lower animals, as it is a power which adds to our comfort in every condition of life. Hence the art of supplying heat has been studied for many years with great attention, and illustrated by men of great skill and talent in the profession.

Still there appears to be a field sufficiently open for new and useful research, as it seems to me it is possible to combine an equal degree of safety, cleanliness, and comfort with health and economy, and prevent some of those wild speculations which some men of the present day indulge in.

The first advantage in the art of supplying heat will perhaps be best given by studying the nature of the material, viz., coal usually employed for obtaining it, and also in endeavouring to ascertain the quantity of heat this material will produce.

In making a few remarks on the construction of fire-places and chimneys in connection with the details (as shown on

* Read before the Society on 25th April 1892.

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the drawings) regarding the management of heat, it will doubtless be considered an advantage to some who have not studied the subject to know whether their grates are formed on good principles or not, and therefore be in a position to choose those which come nearest to the proper form, and which are constructed by suitable materials. There will be a further advantage in directing the attention of the younger members to the study of an important subject, under views considerably different from those in which it has been hitherto presented.

The subject to be considered is the nature of the chimney for close and open ranges (as shown on drawings). For producing heat, and carrying on the work for which they are intended, we must have considerable draught, and this draught depends on the height of the chimney and the area of its section, and also the temperature at which the heated gases and smoke are allowed to enter it.

A high chimney will be found to make a considerable difference in the effect which can be gained from smoke flues, because rather a forcible draught is required to make the smoke circulate through such a distance as will occur in the horizontal and perpendicular flues of ovens.

It takes 300 cubic feet of air at 62° for the combustion of one pound of coal. In passing through the fire, the air is necessarily highly heated, and it leaves the fire at 1200°, and is therefore expanded to nearly $3\frac{1}{2}$ times its original volume; from thence to the chimney it is gradually cooled to 300°, which is $1\frac{1}{2}$ times its original volume.

If the chimney be a low one, the only method of procuring the required force of draught is to allow the smoke to ascend at a higher temperature. We will take the draught of chimneys suitable for kitchen ranges, either close or open.

A column of air in a chimney, say 50 feet high, at 300°, weighs two-thirds of the same height of the external air, and motion will ensue with a velocity due to 17 feet head.

The power of a chimney 50 feet high, 12 inches diameter, attached to a close range, having flues same area as the

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chimney, 22 feet long in circuit from fire-box to throat of chimney. It will therefore be seen that we have to determine the discharge of a pipe 72 feet long × 12 inches diameter with head of ·243 inches of water.

We allow 12 lbs. of coal to be burned in the hour. We have to pass 12 × 450 = 5,400 cubic feet of air per hour.

This discharge 5400 ÷ 60 = 90 cubic feet of air per minute, ·00579 × 24 yards = ·13896 inches of water for friction alone, and adding to this the head due to velocity.

The diameter being one foot, we have an area of ·7854 square foot, and as we have 90 ÷ 60 = 1·5 cubic feet per second; therefore 1·5 ÷ ·7854 = 1·9 feet per second, and with ·93 coefficient, which is due to a head of ·005 inches of water, and the total head for the 90 cubic feet per minute is ·138 × ·005 = ·143 inches of water.

But we had ·243 inches of water to dispose of, which leaves a balance ·243 − ·143 = ·1 inch of water as a reserve.

If the chimney we have just considered had been square, the power would have been greater, in the simple proportion of the area of a square to a circle.

The velocity of discharge is the same in both cases, and the quantity discharged is proportional to the respective areas, or as ·7854 to 1. The top of a chimney should not be larger than that which is required for the greatest quantity of fire.

If it be larger than necessary, the draught will be materially injured by it. The intermediate part of the chimney, between the top and the bottom, should be larger than it is at the top, and as free from abrupt changes as possible. The size of a can for a kitchen chimney should be no less than 12″. For example, the sketches of chimneys, figs. No. 1 and No. 2, will be best understood by showing the discharge of each. Say we require the power of a kitchen chimney, fig. 1, 50 feet high, perfectly straight, and 12″ in diameter. The temperature inside the chimney being 300°, and the external temperature 62°, which gives a head of 17 feet or ·243″ of water. The ordinary discharge of air without friction is $\sqrt{17 \times 8} = 32$ feet per second.

·006 × 16·6 = ·0996″ of water lost by friction, therefore ·0996 × 32 ÷ ·243 = 13 feet lost per second by friction; therefore

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the real discharge of the 50 feet chimney is 32−13=19 feet per second. We will take chimney, fig. 2 on plan, 57 feet long, the height of chimney being 50 feet and the diameter 12″. The temperature inside the chimney being 300° and the external temperature 62°, which gives a head of 17 feet or ·243″ of water to produce motion.

The ordinary discharge of air without friction is 17×8= 32 feet per second.

·006×19=·115 inches of water lost by friction, therefore ·115×32÷·243=15 feet lost by friction, and the real true discharge of the chimney 57 feet long is 32−15=17 feet per second. The difference between the two chimneys being 19−17=2 feet lost on the bent chimney.

The next subject I propose bringing under your notice is the nature of the kitchen range as it at present exists, with objections and suggested improvements.

About 35 years ago the close range was in its infancy, and down to the present time there is no practical difference in its manufacture, the sizes between the flues being the same. When these ranges came from the manufacturer they were nothing more than skeletons or frame work.

When first the close ranges were introduced, the front was built with brick work and the ovens were built into the front, the fire-box being built in with a large metal plate on the top. The medical faculty during the past twenty years have in many instances turned out of their houses the close range, and have adopted the system of open ranges.

As a practical man myself I have studied the question for over 35 years, and having manufactured all kinds of ranges I am in a position to speak.

The construction of a kitchen range for heating ovens and hot water is a matter which requires very considerable care. It is a common fault, when building in kitchen ranges, to allow of such a very large exit for the flame and gaseous matter, that a considerable portion of the heat passes up the chimney, instead of being received by the water in the boiler and heating the ovens. This defect arises principally from the shortness of the boiler and oven flues. This will be better

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understood by comparing drawings Nos. 3, 4, and 5 with Nos. 6, 7, and 8.

It is therefore of the greatest importance to prevent as far as possible the unnecessary waste of fuel caused by defective principles in the construction of flues.

We will take the oven flues on drawings Nos. 3, 4, and 5, showing the present system of building in ranges; the oven flues being contracted with brick, etc., and brick work being a very low conductor, viz., 4·83, so that instead of the heat getting to the ovens and boiler, it is largely carried up the chimney. We will now take drawings Nos. 6, 7, and 8, showing the flues of ovens and boilers built on an improved principle. You will observe that the back and bottom of ovens are nearly all exposed to heated air coming from the fire. The centre division plate marked A, going across from back to front, has a 2″ check going across, which retains the heated air at the bottom of ovens.

On drawings Nos. 3, 4, and 5, the division plate under the oven comes only about one-third of the distance from the back, thus allowing the heat to pass up without heating the bottom of the oven to the same temperature as the top for either baking or roasting. See fig. 11.

The ascending flues of the ovens and boilers on drawings Nos. 6, 7, and 8 are all measured according to the capacity of the chimney, that is, its length and diameter, and the dampers are so adjusted that no more heated air can pass than allow the ovens to be heated to 300°, the hobs to 800°, and the water also heated in the boiler.

Above the ventilating roof plate on the top of range, as shown on drawings Nos. 3, 4, and 5, it will be noticed that there is no building except some shivers and lime put round about the top side of plate to keep the cold air from going in.

While it will be seen from drawings Nos. 6, 7, and 8 that the inside of vent having iron flues coming from the boiler and ovens are built solid into the chimney, the dotted line shows the ventilating damper raised up in the inside of lintel with a square air shaft put into the iron flue, looking upwards. This ventilator always remains open, and carries away all smell caused by cooking and foul air. See fig. 9.

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In drawings Nos. 3, 4, and 5, the ventilating damper being level with the bottom of the lintel allows the foul air to enter the kitchen, and besides cannot be opened without soot falling down and preventing the range from working properly. (See fig. 10.)

Regarding many of the so-called improvements in ranges of the present day, I fail to see that they have resulted in any advantage to the health of the community.

It is not my intention to disparage any maker of kitchen ranges; my aim is to make them all alike, as according to my theory every range can be made to work satisfactorily. Regarding the patent improvements, I will take first the back flue, or so-called open arrangement. What can be the use of it when it is found that the oven and boiler will not heat without being closed?

The rising bottom is called a patent improvement, but it has proved a failure for the last twenty years. The slow combustion arrangement was in use some twenty years ago, and I see the same improvements referred to that are in use now, such as the open arrangement, the rising bottom, and slow combustion.

I have no doubt that some of my readers will have close ranges in their kitchens, and when they enter the house it will not be difficult to tell what is being prepared for dinner. What is the cause of that? It is simple enough according to my idea, seeing the cook cannot open the ventilating damper on the top of the range, as the smoke would come out at the covers and the range cannot be heated. Where are the gases going to? They do not go out by the window but go out by the door, polluting the whole house. Still, in connection with the open arrangement and flues from the boiler with a square connection into one flue, as shown on section, fig. 13, manufacturers have not studied the natural currents of air when they published their directions for building and using this range. They do not seem to be aware, or have ignored the fact, that a current of air naturally takes the shortest way up the chimney instead of passing through the burning fuel. When this so-called open arrangement is used as an open fire, neither the boiler nor oven will heat, as the size of the

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opening being $12'' \times 5'' = 60$ square inches, this admits 240 cubic feet of air to pass in per minute, taking away the whole power of the chimney from the other flues.

Our next subject is one of great importance, that of heating water by different shapes of boilers and systems of pipes. (See figs. 14–19.)

But we do not place any importance on the system of pipes, as we show the methods from their first construction down to those of the present day.

It is necessary that we should clearly understand the motive power which produces circulation, as without this there will be more or less uncertainty as to results, especially in the more complicated forms of it. Though imperfectly understood by most people, and not unfrequently by those who are daily engaged in fixing hot water apparatus, it is the result of an immutable law of nature (the law of gravitation), and it is so simple that, with moderate care in its structure, failures are next to impossible. A very slight experience suffices to show that a pipe taken from the top of a boiler and given a direct or gradual rise to the point furthest from the boiler, and then returned and connected with the bottom of boiler, will upon the application of heat cause the water to circulate; but how many plumbers and hot water fitters can give the reason why it does so, or, more important still, tell when an apparatus will not act, and why it will not?

In reply to the question, What causes circulation? you will frequently hear the reply, "Oh! as the water is heated it becomes lighter and begins to ascend, and the cold water returns to take its place." It is a very common error to suppose that the circulation commences in the flow-pipe or up-pipe, whereas it is just the reverse. The circulation is caused by the water in the return pipe, which, owing to the difference in temperature, is heavier than that in the boiler, and consequently forces the hot water, which is lighter, upwards, and thus sets the whole water in motion. Hence it is clear that the motive power which produces circulation is the difference in weight of the two columns of water, which we will call the ascending and descending columns.

When a plumber is called into a house to state the cause of

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the want of hot water, a large majority of men advise their customers to have their pipes altered in order to get an abundant supply. This is, unquestionably, very erroneous advice.

I have heard papers read on this subject, and when anyone touched on the question, "What produced the hot water?" they always evaded the matter, and stated that "heat was another subject." I would ask the question, What have pipes or a system of pipes to do with the producing of hot water? I will give you a few cases which have come under my notice anent the alterations made on hot-water pipes. A plumber was called into a house in Charlotte Square to remedy the want of hot water; he advised the lady to alter the pipes, which alterations cost £35, yet with no better result. Another case which happened in a well-known hotel in Edinburgh, the plumber advised the proprietor and tenant to alter the pipes from 1″ to 1¼″, and having two fires, a large boiler in each fire, and a storage tank holding 390 gallons of water. After the said alterations the water was not one degree hotter, but proved to be worse instead of better. A case in Queen Street, Edinburgh, where a gentleman put in a new range and new hot-water pipes through his house in an ordinary system for circulation, the gentleman could get no hot water. The ironmonger blamed the plumber, and the plumber the ironmonger. It was agreed between the tradesmen that the gentleman should employ an engineer to act as arbiter between them. The engineer made an alteration; namely, the flow pipe from the boiler was disconnected from the top of tank and inserted into tank near the bottom; still, after this alteration matters were found to be no better. The general answer to these three cases is, that the want of a sufficient supply of hot water was caused by defective flues and the defective heating surface of the boilers, and in all cases where the proper alterations made, the results proved satisfactory. I may add that in the second case the fires were made to one-half of the former size. It was afterwards found that one fire only was sufficient. In the third case the fire was reduced to one-half the size.

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The arrangement of boiler and pipes on Plan (figs. 14–19.) —1st. I will take fig. 14, showing boiler and pipes. The boiler retains the same shape as when first made. It was with difficulty the water was heated without forcing the fire, as the flue was never put under the boiler and up the back. When the system was adopted to put the flue under the boiler and up the back, I have known instances where steam has been generated, which forced the passage up the flow pipe, and sometimes up the feed pipe, with a noise, concussion, and vibration that shook the building, apart from the risk of damage to the property. 2nd. Figs. 15 and 16. These systems were adopted to avoid the bursting of pipes and preventing the noise as already mentioned, but they were found to be a failure with regard to getting hot water.

Boiler on Plan, fig. 16, is the lowest heating power boiler that is applied to a close range. Horizontal surfaces beneath the flame are considered of little or no value; one square foot of heating surface above the flame is equal to two square feet of vertical or side surface, and the bottom remains the same as vertical or side flues.

I would now call attention to the Ell boiler on Plan. Fig. 5 shows present system of building in, and fig. 8 shows the new system.

3rd. Figs. 17 and 18.—These systems are more modern, and considered by some people to be an improvement on the tank and boiler arrangement, where the tank is placed in the kitchen, and which is generally adopted as the system of the present day.

Suppose 100 gallons of water are to be heated from 32° to 210°, the following are results of various tests: Before you can get hot water, the 100 gallons must be raised to the standard temperature of 210°, and you must raise the water up in a solid body, which causes a great waste of fuel and time, etc. Fig. 19 shows a new system of pipes for the circulation of hot water and the economy of fuel. The hot water tank is placed at the top of the house, and the cistern above the tank, with cross pipes inside which are perforated, through which the cold water issues in a spray, and is

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Fig. 4.

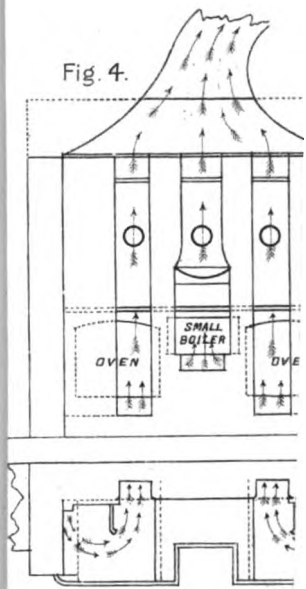
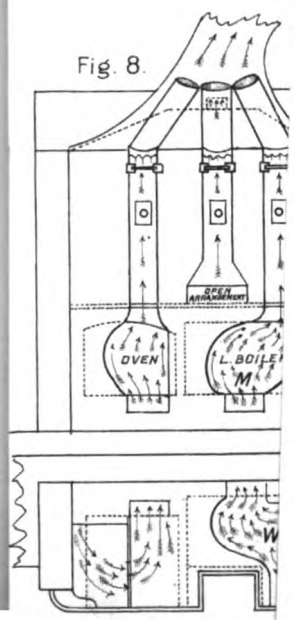


Fig. 8.



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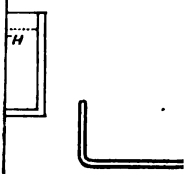

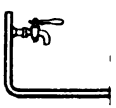

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distributed over the whole upper superficial area of the water in the tank. The return pipe, as is seen in sketch, goes to the bottom of the tank to carry the hot water to that point; the hot water is practically carried from there to the boiler, keeping up the temperature of boiler. From experiments I have myself made, I find that there is a saving of from 15 to 20 per cent. of fuel by this system over all the others which I have had the privilege of bringing under the notice of this Society.

Cycles Past and Present. By G. Lacy Hillier.*

On this occasion I may claim your consideration in that I inadequately represent a better man; I am only the understudy representing the actor who should have been present before you, and as you are well aware the understudy seldom rises to an equality with the original artist. The importance of the cycling sport is not always grasped by persons who have not taken an active interest therein. They are much inclined to regard it as a boy's toy, and have yet to see its importance as a national sport.

There are firms at Coventry turning out 300 machines per week, and finding employment for thousands of operatives; and I hope to show in the course of my remarks that the claim that it is a national sport is not wholly unfounded.

Before a cycle could be a possibility, good roads were necessarily a condition precedent, and in the 17th and 18th centuries that condition did not exist. I do not know whether the cyclist of to-day ever gives a thought to the condition of the highways a century or two back, but I can give you some faint idea of them by quotations from travellers about that time. For example, we find in 1680, in the Privy Records of Edinburgh, "The first 4 miles out of Edinburgh towards London in so bad a state that the passengers were in danger of their lives."

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* Read before the Society, and illustrated by Models, Photos., and Lantern Illustrations, on 22nd February 1892.

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The "Common Carrier from Edinburgh to Selkirk, a distance of about 38 miles, took a fortnight to accomplish the journey, and his neighbours turned out and bade him an affectionate farewell."

In 1685, an Irish Viceroy going from St Asaph to Conway, a distance of 14 miles, took 5 hours to cover the distance.

The death of Charles II. occurred on 6th February 1685, and the news reached Edinburgh by express messenger at 1 a.m. 10th February, taking 3 days, with relays of horses.

In 1708 Ralph Thoresby relates that, riding near Tuxford, the guides were forced to plumb every step of the way to find solid going for the riders; a step to right or left might have been fatal, and even then the water came up to the saddle skirts.

In 1702 there was no stage coach in Scotland.

For all practical purposes, in the year 1700 London was farther from Reading than it is from Edinburgh now, and Edinburgh was farther from London then than Vienna is to-day. Even when stage coaches began to run and the highways were accordingly improved, they did not attain very great speed, and their journeys were fraught with many dangers, as witness the following notice, still to be seen at the Black Swan at York: "York 4 days' coach begins the 18th April 1703. All that are desirous to pass from London to York, or from York to London, or any other place on that road, let them repair to the Black Swan in Holbourne in London, and to the Black Swan in Coney Street, York, at each of which places they may be received in a stage coach every Monday, Wednesday, and Friday, which performs the whole journey in 4 days, if God permits." The distance was 199¼ miles.

As compared with this let us look at the record made upon a cycle from York to London by Mr J. M. James, a member of the North Road and Stanley Cycling Clubs, who covered the distance in 14 hours 22 minutes.

Not only were the roads in England little better than tracks, and deep in mud,—so deep in fact that the traveller had to have a guide in front of him, probing the depth of water and mud with a staff to find hard ground for the horse

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to travel upon,—but the same state of things obtained in Ireland, where the roads were even worse than those of England. I do not propose to trouble you at any length on this point, but I will merely quote to you as characteristic a little couplet written, it is unnecessary to add, by an Irish poet upon General Wade, who practically constructed some of the best roads in that country. The poet says—

> "Had you but seen these roads before they were made,
> You would lift up your hands and bless General Wade."

At the present time an agitation for the improvement of the highways is going on in the United States, where, in the outlying districts, the roads are even worse than they were in England two centuries ago.

In 1715 the post from London to Edinburgh took 6 days. In 1765 the journey was made at the rate of 3¼ miles an hour. In 1760 the pace had increased to 6 miles per hour; and in 1798 Lord Campbell made the journey in 2 days and 3 nights, 96 hours in all, but records in his memoirs that at that time the pace was so rapid as to be considered dangerous, and that there were rumours that persons travelling by the coach after reaching London with such celerity died of an affection of the brain. I have not been able to ascertain that there was any truth in this statement, but I may note that in 1891 Mr T. A. Edge, mounted on a machine fitted with the "CLINCHER" tyre, rode from London to Edinburgh in 38 hours 44½ minutes.

These facts will explain to you why the Cycle is to a great extent a modern development, for although machines of the "Velocipede" type were frequently experimented with, they could not possibly have been successfully used upon highways in such a condition as I described to you. As early as 1691 we find that on 12th June John Greene took out a patent for new engines or carriages driven or drawn by man or beast; but details are lacking, and the exact nature of Greene's "engines" are unknown. In 1787, 12th May, G. Watkin patented Roller Bearings, and in 1794, 12th August, Philip Vaughan patented Ball Bearings.

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There is an old couplet which says :—

> "Things by the ear received men's minds excite
> Much less than when submitted to the sight."

I propose to show you on the screen pictures of some of the earlier forms which the "Velocipede" took. The first picture will be, I think, the actual representation, or a very close copy, of a machine invented by "John Vevers, Master of the Boarding School at Reigate in Surrey," a full description of whose vehicle was printed in the *London Magazine* (fig. 1).

This is described as a "travelling chaise" without horses; the rider seated in the carriage is only engaged in steering, whilst the other person hanging on by a strap behind is working a complicated arrangement of springs and levers which is supposed to propel the machine. This was invented in 1766, and an improvement thereon was invented in 1779 by M.M. Blanchard and Mesurrier and illustrated in the *Journal de Paris* in the same year. This machine was exhibited in the courtyard of the Palace at Versailles before Louis XVI. and Marie Antoinette. There was much wisdom in the remark of one of the early inventors, who said, "The velocity of these carriages depends on the activity of the manager."

The next picture is of a machine invented in 1804 (fig. 2). It is very fortunate that the artist has provided the person driving with so well developed a biceps muscle; for, as will be noted, in addition to the "driver," seats are provided for no less than eight other persons, and that he is thrusting away from him. Perhaps this is why the machine is geared down to 15 or so.

In 1816 a machine, a number of pictures of which I will now give you, was invented by two brothers named Nicephore and Claudelle Niepice, one resident at Paris and the other in Hammersmith (figs. 3, 4, and 5). The machine was ridden in the gardens of the Luxembourg, and was called the "Celeripede." The rider was seated across a bar to which was affixed two wheels, one of which steered in the usual way. Progress was obtained by striking with the feet alternately on the ground, a fast speed being attainable.

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The next picture is that of the invention of Dennis Johnson, a coachmaker of Longacre, and it was called the "Pedestrian Curricle" (fig. 6). The rider is in the costume of the period, the picture being taken from an old print. In the background is seen the manner of attaining pace. The means of progression remind one of the Irishman, who, being carried home in a sedan chair without a bottom, said, "But for the dignity of it, there was no advantage in the arrangement." The wits of the day asserted "that the dandy rode in his carriage and walked in the mud at the same time." In 1818 an improved "Dandy Horse" was invented by the Baron von Drais, Baron Drais de Saverbrun, Master of Woods and Forests to the Grand Duke of Baden, who resided at Mannheim-on-the-Rhine. The machine was called the Draisnene, Draisienne, or Drasena, and the patent specification was issued on 17th February 1818 to Louis Joseph Dineur of Paris. Baron von Drais died in 1851.

The Baron was a record maker. *The Repository of Arts* for 1st February 1819 contains an account of "the pedestrian's hobby-horse." The *Repository's* contributor waxes very enthusiastic over the hobby-horse of the Baron, of which he writes thus: "The swiftness with which a person well practised can travel is almost beyond belief; 8, 9, or even 10 miles may be passed over within an hour on good level ground. The inventor, Baron Von Drais, travelled last summer, previously to his last improvement, from Mannheim to the Swiss relay-house and back again, a distance of 4 hours' journey by the posts, in one short hour." It will be noted that the best pace claimed for the "Baron" was 10 miles an hour; and as he covered four posts' journey in that time, we arrive at the result that the pace of the posts was $2\frac{1}{2}$ miles an hour.

In 1824 a journal with the remarkable title of *The Mechanics' Magazine, Museum, Register, Journal, and Gazette,* contains a description of a sarcastically named "Self-Moving Carriage" (fig. 7); it runs thus: "Mr D. McDonald of Sunderland informs us that he has invented a 'Self-Moving Carriage' for travelling on roads, which has carried seven persons. It is propelled by means of treadles. A man sits

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behind working the same, and there is a fly-wheel operating upon two cog-wheels, which operate upon a square axle. You will perhaps think that the man behind has hard labour. Not so; from the velocity of the fly-wheel, together with the aid of a lever, which is in the hand of a person in front steering, he has not often to put his feet to the treadles. Mr M^{c}Donald intends, when he shall have improved the friction of the body of the carriage, to present the same to the Society of Arts; and as he desires to receive no emolument for the same, he hopes it will come into general use." I have made this quotation because I do not know whether Mr M^{c}Donald's sarcastically named "Self-Moving Carriage" was presented to your Honourable Society; possibly its merits may have escaped your attention.

The next picture is a French patent of 30th June 1830 (fig. 8). The machine is driven by pressing the feet upon projections on the secondary wheel rim; no steering gear or brake are provided, and this is merely interesting to show the wild ideas which some inventors have taken into their heads. I do not understand how the rider could have retained his balance; but you will observe that he is dressed with great care, to indicate, presumably, that he was undergoing little or no exertion.

In 1830 Dreuze in France mounted the postmen in country districts upon "Dandy Horses," but a very heavy winter accompanied by much snow prevented their use and the matter dropped. I merely introduce the next picture as illustrative of the complications which inventors would introduce.

In 1836 Michael Faraday rode a "Dandy Horse" in the neighbourhood of Hampstead, and the Duke of Northumberland rode and came a complicated "cropper" off one of these vehicles at Alnwick Castle.

Credit has been generally given to Gavin Dalziel, a cooper —also described as a merchant—of Lesmahagow in Lanarkshire, as being one of the earliest, if not the earliest, inventor of this bicycle. He was born in 1811 and died in 1863.

A discussion is now going on in the *Glasgow Evening Times* claiming the honour for Kirkpatrick M^{c}Millan, a blacksmith of Courthill, Keir, or Penpont, Dumfriesshire, in 1840–45.

Gavin Dalziel's invention (fig. 10) has been preserved. It is

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a rear-driving safety, the foot power being applied to levers attached to cranks on rear wheel.

Thomas M^c^Call (figs. 11 and 12) states that cranks and connections were first fitted about 1845 by Peter M^c^Millan, working at Drumlanrig Castle as a blacksmith, and later at Penpont, Dumfriesshire.

Kirkpatrick M^c^Millan was confined, prior to 1845, in Glasgow prison for causing an obstruction owing to the crowds attracted by his machine. It has been ascertained that he made a "Dandy" in 1834, and the actual evidence as to where he fitted driving gear and levers to it seems as yet somewhat hazy.

The direct pedal action on a crank on the front wheel was first applied to a tricycle by Messrs Mehew of Chelsea, and the machine was shown in the Exhibition of '62. It seems probable it was seen there by an ingenious Frenchman named Pierre Lallement, as on 20th November 1866 he affixed a pedal and crank action to a bicycle (fig. 13). The pedals are placed upon the cranks in the ordinary way, and, as you will notice, are fitted with balance weights to keep them in the right position to catch the feet. It is curious that Lallement was anticipated by a caricaturist who drew the Prince Regent, early in the century, driving the front wheel of a "Dandy Horse" with cranks.

The "Cantering Propeller" (fig. 14), invented by E. Landis of Baltimore, 24th July 1860, anticipated in principle the rear-driving safety. The machine is simply a child's toy—a rocking-horse which will progress on the highway; I only notice it here because it anticipates the rear-driving of cycles. The long bar in the rider's hands is merely used for steering purposes, but the rear part of the rocking frame is connected by a bar with a cranked axle, which drives the rear wheels.

My next picture is a tricycle to be drawn by turnspit dogs running inside the front wheel (fig. 15). This I only show as a sample of the sort of absurdity of which some inventors are guilty. It was patented in America by F. H. C. May of Buffalo in 1870. The author of the book from whence I extract it remarks "that he does not think that two 40 lb. dogs would be able to drive a 200 lb. vehicle and an 150 lb. lady."

The first bicycle illustrated in England appeared in *The*

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English Mechanic of 28th June 1867. This, however, was called a "Velocipede" (fig. 16).

In 1866 Messrs Michaux & Cie showed a perfected Velocipede at the '67 Exhibition, and it was seen in Paris by Rowley Turner as a child's toy. He persuaded the makers to construct him a machine of a more substantial type, and this was brought to Spencer's Gymnasium in 1869. Mr Turner was a relative of the then manager of the Coventry Machinists Company, which was engaged in the manufacture of sewing-machines, a trade which had been considerably cut into about that period. The Coventry Machinists Company took the matter up and succeeded in creating a large business.

The next picture I shall show you is interesting only as being that of the machine which was first called a "Bicycle," in Leftwich's "Specification, 19th July 1869"; being the first instance in which that word was used in the Patent Office (fig. 17).

I shall now show you a series of pictures of machines illustrating the manner in which the cycle has developed.*

The Hon. Ion Keith Falconer did more for cycling at the universities than any other man: he was a splendid fellow. He died in Arabia a few years ago.

Present record for 50 miles: ordinary, 2, 45, 55; safety, 2, 24, 44.

Some people still cling to the notion that more can be done with the arms than with the legs.

The subject of military cycling is a very large one—so large indeed that I will not venture to trench upon it this evening. Although successfully taken up of late, the idea is not a new one, as in the course of my researches I find that so early in the history of our sport as 1820 a poet had delivered himself of the following lines:—

* Fig. 18, French Boneshaker; fig. 19, English Boneshaker; fig. 20, Phantom Bicycle; fig. 21, Wooden Bicycle; fig. 22, Bicycle of John Keen; fig. 23, Aerial Bicycle; fig. 24, Germ of Safety, Lawson's Patent; fig. 25, Otto or Dicycle; fig. 26, Sociable Tricycle; fig. 27, Early Cycle, still in use; fig. 28, Early Racing Cycles; fig. 29, Racing Machine, weighing 30 lbs.; fig. 30, Manu-Motive Cycle, "The Jubilee"; fig. 31, Racing Bicycle, 1887; fig. 34, "The Extraordinary"; fig. 36, "Kangaroo"; fig. 37, "Cantering Bicycle"; fig. 38, American Track.

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"Our wooden walls were long the patriot's toast,
Soon wooden cavalry will be our boast.
And when some Wellington to conquest leads
A new-built squadron of velocipedes,
What foe will dare our prowess to withstand,
Borne on our native oak by sea and land."

The picture illustrates Singer's "Victoria" sixteen in hand (fig. 32), which was used by Singer's band at Harrowgate Camp in 1889. This machine was a great favourite at Aldershot as a military cycle; and as Major Fox, who had to do with the training of military recruits, from a gymnasium point of view found it singularly useful, I lean to the opinion, based on my own experience, that it was a particularly useful engine for getting up one's muscle, especially if two or three of the riders were passengers. It was, however, very unhandy, and if run up a narrow lane, difficult to extricate.

The military machine is now a rear-driving safety, with fittings to carry rifle and bayonet; it is very handy and quick, and at the same time fast.

At the end of 1891 the B Troop of the 26th Middlesex Cycle Volunteers, under Captain Phillips, rode 100 miles in 10 hours.

The ordinary bicycle had reached its zenith as a solid-tyred machine, and the safety bicycle was coming to the front.

This is a picture of Mrs Smith on a tricycle (fig. 33); she was the pioneer of lady cyclists, and has probably done more than any other lady to encourage the sport among her sisters, amongst whom it has already found wide favour. In the *Illustrated London News*, about three weeks ago, there was given an illustration of two ladies riding tricycles as symbolic of the emancipation of the fair sex.

This machine was one of the first examples of the now successful front-steering tricycle. The frame, it will be noticed, is very crowded indeed, and the front wheel very small. The machine was thoroughly tested, and developed into a highly successful vehicle (fig. 35).

I give you this picture, which is always given at all gatherings of cyclists, representing what the Earl of Albemarle calls the "Mecca" of all good cyclists. Ripley (fig. 39) stands

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upon the direct Portsmouth road, which is always in very good condition, which it probably owes to the fact that, long before the days of Macadam, it was made with broken granite taken from Newark Priory, which stands within two miles of the village. This priory, one of the richest in the southern counties, covered an immense extent of ground. The walls were built of flint "rubble" and faced with the very best granite. After the dissolution of the monasteries, the facing-stones were taken off, and, according to contemporary chroniclers, used to mend the important highway which connected the arsenals of London, Gravesend, and Portsmouth. Facing the inn is the old manor-house where the legend has it Queen Elizabeth stopped after reviewing the troops at Tilbury Fort when on her way to inspect the garrison at Portsmouth. In the background may be seen the spire of Ripley Church. The vicar, Mr Henry Hooper, noticing the number of cyclists who visited the village on Sundays in the summer, determined to institute a cyclists' service, lasting some 20 to 25 minutes. The organ is played and the lessons read by cyclists, and on an occasion, as for example when the American touring party visited the village, a cycling clergyman assisted in conducting the service. The example set by Mr Hooper has been followed in many parts of Great Britain, in America, and in Australia, on the suggestion of cyclists who have visited this little village, as historical as any place could be in connection with so young a sport as cycling.

We now come to a period when it was considered by a large number of persons that cycling had reached its zenith, when no further radical improvements could be made, and that only in improvements of detail would novelties be found. Just at this juncture the air tyre was invented, and a complete revolution introduced into the sport (fig. 40). A Mr Thomson in the year 1845 had applied air tyres to the wheels of vehicles, and had anticipated in many important points later inventions, and it seems strange that these inventions should not have been more successful at the time.

Three or four years ago the son of a veterinary surgeon resident in Ireland, named Dunlop, was riding the solid-tyred machine; and suffering from headache, this induced his father

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to construct for him air tyres, with the result that the well known "Dunlop" tyre was put in the market. For reasons which I will presently explain, this tyre possessed many disadvantages; it burst, punctured, and slipped, and secured an unenviable reputation for air tyres generally.

The "Clincher" tyre, the construction of which I have already illustrated to you by means of lantern slides, has been introduced, and at the close of the lecture I will give you my views thereon; but first I will tell you what has actually been done on air tyres: one mile in 2 mins. 16 secs. from a standing start upon a specially prepared track. This is faster than man has ever gone by his own muscular exertion alone, and is equal to a speed of 26½ miles an hour.

Professor Huxley said before the Royal Society that "no improvement had added anything to the speed or strength attainable by the unassisted powers of man." The Professor probably meant that neither stature nor the speed of man had improved since Homer's day; but a man can propel a cycle by muscular power alone at a pace which would have put Achilles to shame, and over distances which would have utterly astonished the heroes of the Homeric world. Twenty-four miles have been ridden in 60 mins. 40 secs., 100 miles in 5 hrs. 27 mins. 38 secs.; in 12 hrs. 192½ miles have been ridden, and in 24 hrs. 361¾ miles.

Land's End to John o' Groat's, 861 miles, was ridden in 5 days 1 hr. 45 mins., and the rider only slept 6 hrs. on the trip. This was in 1886. In 1891 the distance was done on a safety in 4 days 11 hrs. 17 mins., and the rider slept for many hours within four miles of John o' Groat's.

The journey from London to Edinburgh, or *vice versa*.—F. W. Shorland did the distance in 44 hrs. 49 mins. on a solid. T. A. Edge did the distance in 38 hrs. 44½ mins. on a "Clincher."

London to Brighton and back.—C. A. Smith did the distance in 6 hrs. 52 mins. 10 secs.

The late James Selby in July 1888 drove the Brighton coach from the White Horse Cellars to the Old Ship at Brighton, with 16 changes of horses, in 7 hrs. 50 mins. The distance is about 108 miles.

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Clincher Tyre Manufacture.

Rim Manufacture.—Sec. No. 1, fig. 41. This shows a short piece of steel as received from the rolling mills. This is passed through a series of rollers as shown in Photo. No. 45; said rollers being numbered in pairs 1, 2, 3, 4, respectively, the top rollers being adjustable, from which it emerges having its edges turned inwards, as shown in

Sec. No. 2, fig. 41. This is again run through another series of rollers, as shown in Photo. No. 45; said rollers being numbered in pairs 5, 6, 7, 8, respectively. It is now in the shape required as shown in

Sec. No. 3, fig. 41, and is ready for bending into the required diameter of rim, Photo. No. 46. The rollers in this machine are three in number, two below and one above, the latter being adjustable, the shape of the rollers being the same as rollers No. 8 in Photo. No. 45. The circled rim with ends overlapping is now taken to the sawing machine, Photo. No. 47, and the ends are cut off, leaving the rim the diameter required; then each end is drilled with three holes and plates fitted on as shown.

Sec. No. 4, fig. 42. Then they are riveted ready for brazing, as seen in

Sec. No. 5, fig. 42. The process of brazing is seen in Photo. No. 48, and the grinding in Photo. No. 49, and the finished joint in

Sec. No. 6, fig. 42.

Sec. No. 7, fig. 43, shows an oblong hole punched in the rim for the nipple.

Sec. No. 8, fig. 43, shows the hole expanded and the brass nipple in place ready for soldering. When this is accomplished the rim is complete, as seen in

Sec. No. 9, fig. 43, in which is placed a section of band and tube, with valve tube attached, fitted with valve and valve cover.

Tube Manufacture.—The inside tube is made of the very best quality of rubber, and is joined round a core of suitable diameter, a lubricant being used to prevent its adhering thereto. It is then placed in a machine (see Photo. No. 50) and has two or more plies of cloth (frictioned) coiled round it, and a thin layer of rubber on the outside. Both the cloth

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and the thin rubber covering are cut slightly diagonal at either end, so that when coiled round they present stepped ends. The core or mandril is now withdrawn and the ends brought together and joined, and a small hole cut through the tube, see

Sec. No. 10, fig. 44. Over this hole the valve tub is placed, see

Sec. No. 11, fig. 44. Then the join of the tube is completed by the use of a tapered piece of frictioned cloth, cut to fit into the steps at either end (now joined). This process is shown in

Sec. No. 12, fig. 44. This piece of cloth is finally covered over with a thin layer of rubber, which completes the making of the tube, see

Sec. No. 13, fig. 44, and Photo. No. 51.

Band Manufacture.—These are of simple construction, and may be described as bands of rubber of varying thicknesses, widths, and diameters, with a ply or plies of frictioned or coated cloth round their inside diameters; said cloth being coiled or folded on either side so as to strengthen and thicken the edges and form the "clinch"—the essential feature in the "CLINCHER" combination rim and pneumatic tube and band tyres.

Sec. No. 14, fig. 52.—Racing Band.

Sec. No. 15, fig. 52.—Semi-Racing Band.

Sec. No. 16, fig. 52.—Roadster Band.

For the fitting up of tyres and rims see Photo. No. 53.

In the section shown you from the screen, you will notice what I consider to be the crucial point in the whole question of air tyres. Under lateral pressure the "Dunlop" tyre is quite unsupported, and gives way in the manner shown in the diagram (fig. 54). If you follow a rider of this tyre, and watch carefully the saddle standard of his machine, you will notice that it is in constant motion from side to side, to counteract the alterations of the centre of gravity, due to the slight but highly important lateral movement of the tread of the tyre. Referring now to the diagram of the "CLINCHER" tyre (fig. 55), which I may in passing remark has been drawn in a somewhat exaggerated manner, for in my experience I have never seen such a great amount of lateral distortion. You will notice that the tyre has a large share of lateral support. I decline

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to believe, as some people would seek to persuade us to do, that you can draw a line from lip to lip of the "CLINCHER" rim and assert that the compressed air within the rim is giving no cushioning advantages as compared with the air of the "Dunlop." As long as the edges of the rim do not touch the road, so long will the rider be "air borne," and I consider that a given volume of compressed air is equally effective in each case; but in the case of the "CLINCHER," the tyre possesses a greater lateral stability, and consequent absence of shift. This, in the case of the "Dunlop," any rider can test for himself by putting his foot upon the rim between the spokes of the wheel.

In considering the value of an inflated tyre, it becomes necessary to face the fact that all tyres are puncturable. It is impossible to conceive any form of air tyre which cannot be rendered perfectly useless and the air chamber punctured by the use, let us say, of a carving-knife or a razor. Facing this condition, it remains to be seen which tyre is the safest, most effective in action, and most easily mended; and, having had unique opportunities of testing almost every tyre in the market, I have arrived at the conclusion that no tyre meets all the requirements so well as the "CLINCHER." Were I going for a long tour upon the Continent, or abroad, I should not follow the example of a young friend of mine, who had the "Dunlop" tyres removed from his wheels and temporarily replaced by "cushions"; I should certainly adopt the "CLINCHER" in its roadster form as the most suitable, most reliable, and most effective of all the inventions of this sort at present in the market. I lay upon the table a section of the valve, a most important part of an inflated tyre, which I have found in actual use to be in every way reliable and effective, and I also show you a larger number of sections of the tyre at various stages of construction.

I have to thank you, Mr President and Gentlemen, for the attention you have given me. If I have persuaded you that the sport of cycling is worthy of your attention and support, whether we regard it as a purely recreative exercise, or from its economic side (in the form of the Carrier Tricycle), I shall be satisfied. I consider it second to no other sport followed

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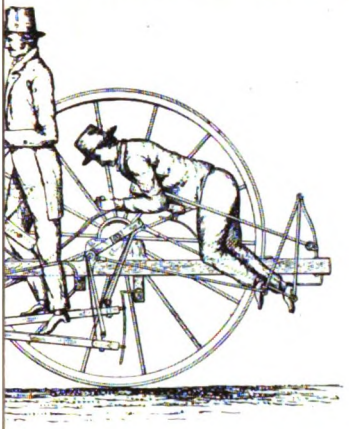

FIG. 7.

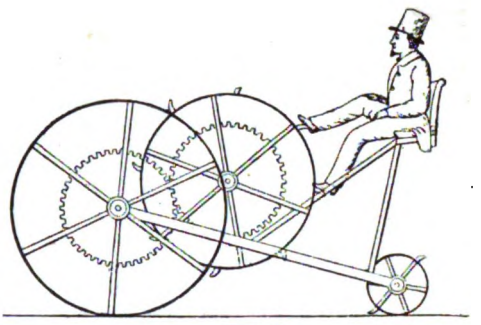

FIG. 8.

FIG. 15.

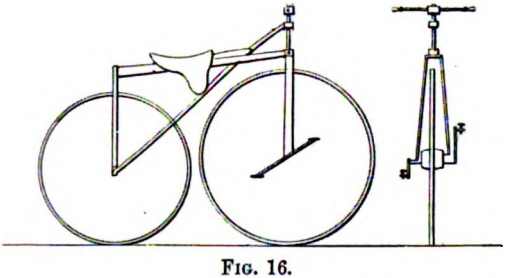

FIG. 16.

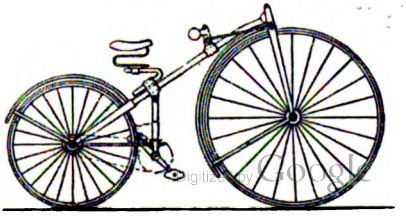

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Fig. 30.

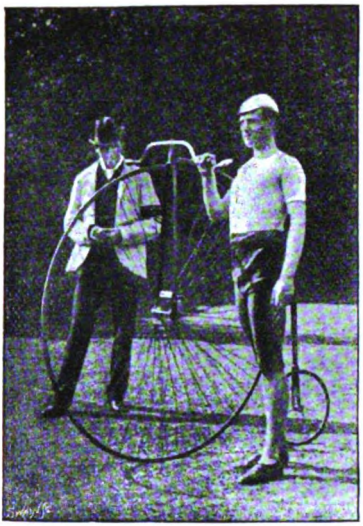

Fig. 31.

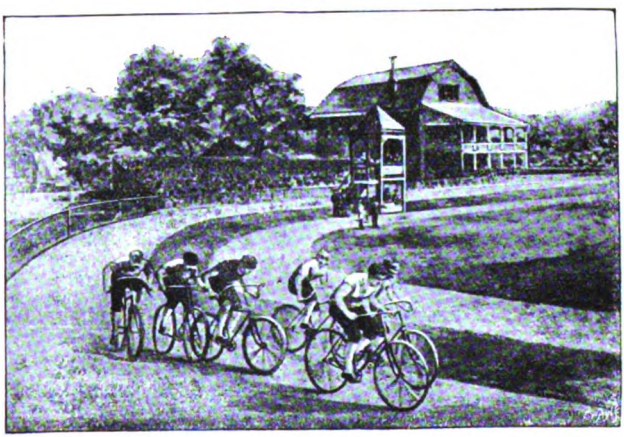

Fig. 38.

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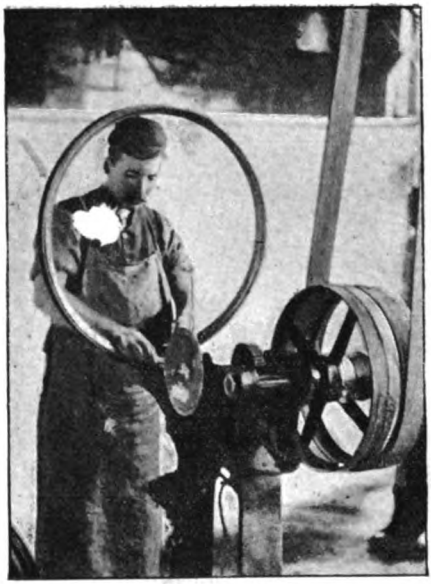

Fig. 47.

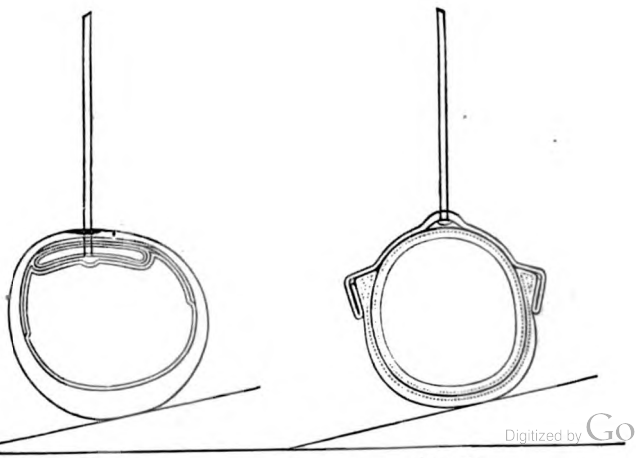

Fig. 55.

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in this kingdom. There are sports that demand violent exertion spread over a short space of time; there are sports which are purely competitive, and have no attraction for the weakly; but cycling is a sport which combines the advantages of skill and strength, so that the physically weak man can often acquire sufficient skill to put him on a par with his more clumsy, if more muscular companion.

In conclusion, I will only say how grateful I am to you for your kind attention, and, in the words of Sebastian in *Twelfth Night*, "I can no other answer make but thanks and thanks."

Electric Traction. By M. Holroyd Smith, M.I.E.E., M.I.M.E., &c.*

Introduction.—It was with considerable hesitancy that I accepted the invitation of the Secretary of this institution to submit a paper on Electric Traction. So much is constantly appearing in the technical press on the subject that it is difficult, if not impossible, to add anything that is new and important; and I fear also the danger of being too simple and rudimentary, on the one hand, or too technical on the other.

Though this Society cannot be regarded as a "popular audience," it may be safely assumed that only a few of my listeners are experts in electrical science, and they, I am sure, will pardon me if, for the benefit of those less favoured, I travel over well-known paths.

Another reason for hesitation lies in the fact that it will be difficult for me to speak upon this subject without frequent reference to my own work, and on this account I must ask your indulgence.

What electricity is it is impossible to say; we do not know, nor shall we ever know. Like the questions "What is life?" "What is matter?" it must remain unanswered; but, though we do not know what it is, we know many things about it, and are constantly learning more. We can produce

* Read before the Society, on 23rd March 1891.

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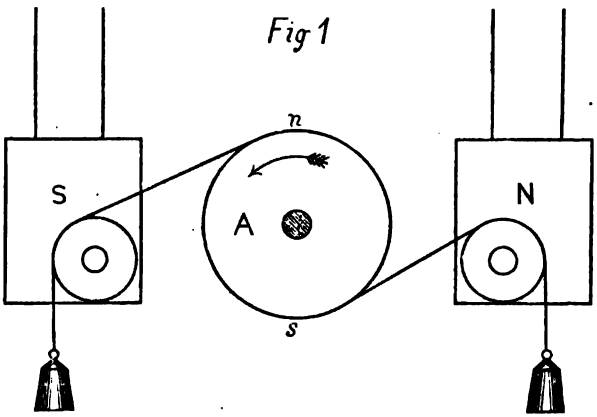
and measure it, direct and control it, and make it serve a hundred useful ends.

To a novice it might seem that there was nothing in common between the attractive and repellent action of a piece of rubbed amber,—the northward pointing tendency of a steel needle after it had been rubbed with loadstone and the vivid flash of blinding light that precedes a thunder-clap; yet, this is so. They are all attributable to the same cause, that mysterious mode of motion which we call electricity. The great world itself may be regarded as a huge dynamo, and there is truth in the saying, "Electricity is life."

Let us take one of these well-known facts, the mariner's compass, and see how far its action will enable us to understand an electric motor.

Fig 1



A steel needle when rubbed with a loadstone becomes a magnet, and will attract other pieces of iron and steel; if allowed to swing free in space, it will turn one end northward and the other end southward. Bring two of these needles together and it will be found that like poles repel, and opposite poles attract each other.

All iron is slightly magnetic; all iron will become strongly magnetic if a current of electricity be made to pass round it.

Take these few statements as the A B C, the leading principles, which, if fully realized, will enable us to understand an electric motor.

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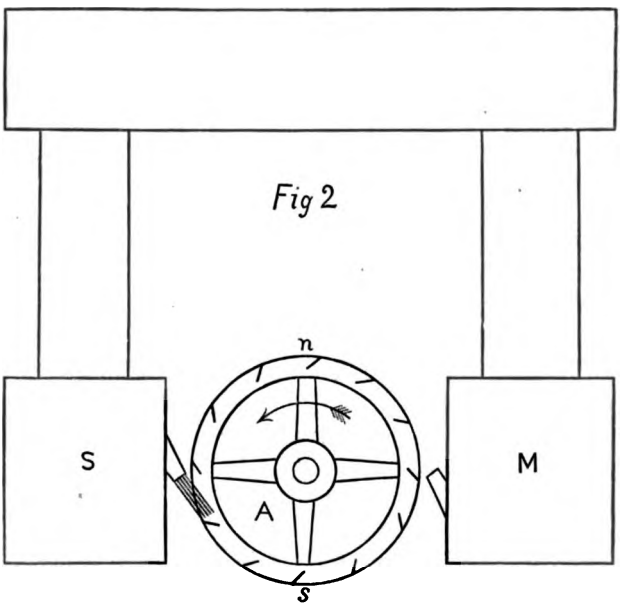
As the terms "lines of magnetic force" are meaningless words to those unacquainted with electrical science, it will, perhaps, be well to try and explain what takes place by the use of mechanical terms and illustrations.

Let *A*, fig. 1, represent a drum or barrel with two long cords wound round it, the end of one cord passing round the pulley in the box *S*, the end of the other round the pulley in the box *N*. Now, if weights be attached, these cords will be pulled off the drum, making it revolve.

Notice, they are always pulling from the points *n* and *s*. This may be taken as illustrating the magnetic *attraction*.



Referring to fig. 2, if *A* is a little water-wheel placed between two pipes, *S* and *N*, connected to a cistern full of water, and the water be allowed to flow from the spouts and impinge on the water-wheel, it would be forced round as long as the water supply lasted. This may be taken as illustrating the magnetic *repulsion*.

If, now, we make the cistern a mass of iron and the pipes bars of iron wound with copper wire, and put heavy masses of iron at the bottom, shaped as shown at *S* and *N* in fig. 3,

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and instead of the pulleys or water-wheel we take an iron ring or cylinder also wound with copper wire, and allow a current of electricity to pass through the wire, the iron will become magnetic and the "armature" *A* will revolve in the direction indicated by the large arrows, because the magnetic force is acting as indicated by the little darts; the dotted darts represent the repelling action, the other darts the pulling action.

Now, inasmuch as the armature revolves in the direction shown, because the left hand pole of the field magnet is *S* and

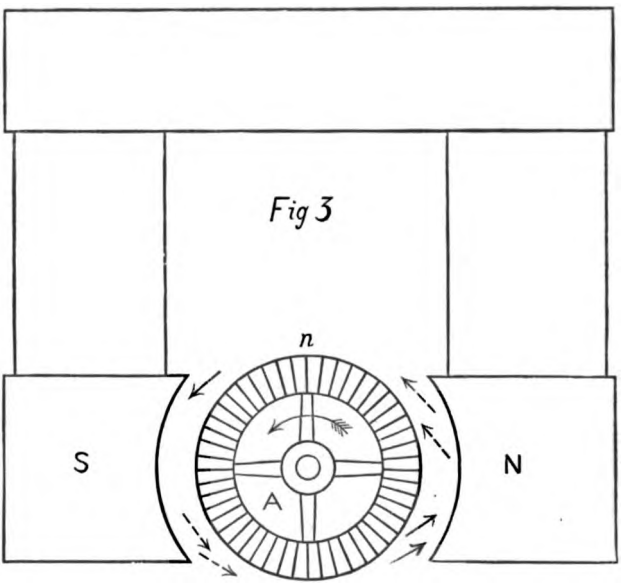

Fig 3

the right *N*, it follows that if their polarity is changed, the polarity of the armature remaining as before, it will and must revolve in the opposite direction. This change of polarity is easily accomplished by causing the electric current that flows round the cores of the magnets to flow in the opposite direction.

How that portion of the armature ring situate at *n*, *s* *maintains its signs*, viz., how the northness and southness remain there whilst the iron itself is being rapidly revolved, that northness and southness being the reason of the revolution, would take too long to explain. Sufficient to say that this *is*

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accomplished, and the parts fulfilling the object are called "commutators" and "brushes," two important and troublesome items in electric-traction work.

The foregoing description will show how essentially the electric motor differs from the steam-engine, with its cylinder, reciprocating piston, crank and fly wheel, and complicated link motion and double eccentric for reversal. No coal, no smoke, no ashes, no water, no steam, no noise, and considerably less trouble in management, less cost, less risk, less liability to derangement, a few hundredweight instead of a few tons to move along.

Let attention be drawn to a point of difference between a steam-engine and an electric motor, *not in favour of* the latter, a fact, which the failure to fully recognize has led to many failures in the use of electric motors.

The revolution of the engine-crank is due to the pressure of steam admitted into the cylinder; if the load be too heavy or the hill too steep, the engine can't move, although the valves are wide open and the full boiler pressure is acting upon the piston. What is the result? Simply that the cylinder containing the steam may be regarded as an extension of the steam-space of the boiler; the parts are all strong enough to bear the pressure, and if the engine does not move, nothing comparatively is wasted. The load must be lightened, or engines with larger cylinders must be employed.

The revolution of the armature of an electric motor may be regarded as due to magnetic attraction and repulsion, as previously explained that magnetic action is due to the flow of electricity through the wires that surround the magnets and armatures. The greater the flow of current the greater the magnetic force, and, therefore, the greater the torque, or turning power of the armature.

But assuming again that the load is too heavy or the hill too steep, the cars stopped do not, as in the case of the steam-engine, stop the waste of energy, but permit a greater waste. There is nothing but the resistance of the windings of the motor to prevent the full flow of the current; and unless the car moves or the electricity is switched off, the wires will probably be burnt through and the motor spoilt. This is one

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of the reasons why, in my first work, I adopted the gramme ring instead of the drum armature, and why, after much experience, others are now doing the same.

If, therefore, a motor restrained from movement permits a waste of electricity, it follows that the quicker the movement the less the *waste*. Hence all electric motors to be simple and efficient must revolve at a high rate of speed. This is a source of trouble and difficulty in their application to traction work, necessitating the introduction of reducing gear.

Perhaps no part of electric traction work has received more attention and absorbed more money than this of gearing.

If the important items of first cost and available space were not prohibitory, the motors might be applied to tramcars, having armatures acting directly upon the axles or wheels. Given a new design and structure of car, this may be economically possible, but for the present, gearing of some form must be regarded as a necessary concomitant, no matter how objectionable.

If, when a motor is revolving at a high rate of speed, it gives the greatest efficiency, it follows that those who have given attention to this subject should try and devise some sort of graduated gearing that will permit the motor always to run at its best speed and the relation between it and the axles to vary. Say the motor runs at 100 revols. per min., and it is desired to start the car, and for the first half minute the speed of the axle is 10 revols. per min., then the relation would be 100 : 1. At the maximum speed of 10 miles an hour the speed is say 100, then the relation would be 10 : 1. Though not stating that this problem is insolvable, it may be safely asserted that no economic method has yet been advanced.

Economic in this sense comprises not only the loss in transmission, but also first cost, applicability, wear and tear, maintenance and renewal.

Devices for this purpose are so constantly being re-invented, that with the object of preventing thought, time, and money from being expended in their repetition, it would be well to put some of them on record.

Let *A*, *A* (fig. 4) represent the axles of a tramcar, *B*, *B* the

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wheels, *M* the motor having a small pulley on its armature spindle communicating motion by means of a belt to a large pulley on the cone shaft *C*. A second belt passing from *C* to C_1 will vary the relative speeds of these two shafts, according to the position it is made to assume. When the car is standing and it is desired to start, the belt would be at *x*; when the car has started the belt may be gradually slided to *y*. Motion may be communicated to the axle either by belting or gearing *f*, *f*. This has not only been proposed, but I believe actually tried. Of course the slipping of the belts, the difficulty of sliding to and fro, renders it impracticable.

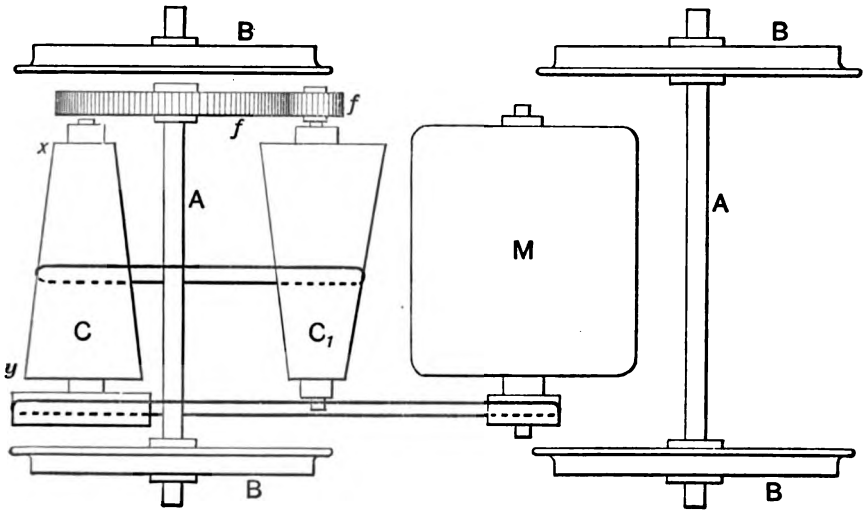

Fig. 4.

A better method is the following (fig. 5):—*M* is the motor, having a bevel pinion, 1, keyed on, its armature spindle actuating the two bevel wheels 2, 2, which will of course run in opposite directions, each bevel wheel having on its inner face a smooth disc, 3, 3, pressed inward by an arrangement of springs. These discs nip a small rubber pulley, 4, on the end of a spindle, free to slide in and out of the second bevel pinion, 5, which gears with the wheel keyed on to the car axle. It is obvious that the nearer the pinion is to the centre of the discs the slower its speed, and the further it is drawn out the greater its speed.

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I am not aware that this has been put into operation. My

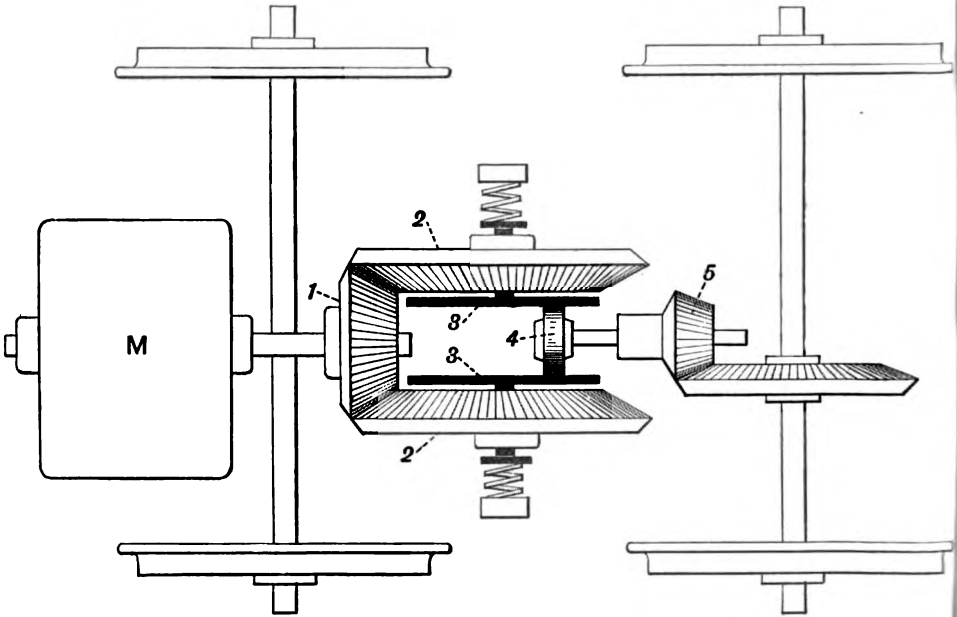

Fig. 5.

objection to bevel wheels under any circumstances led me to be content with simply devising the movement.

Let me now describe a more plausible method (fig. 6). The

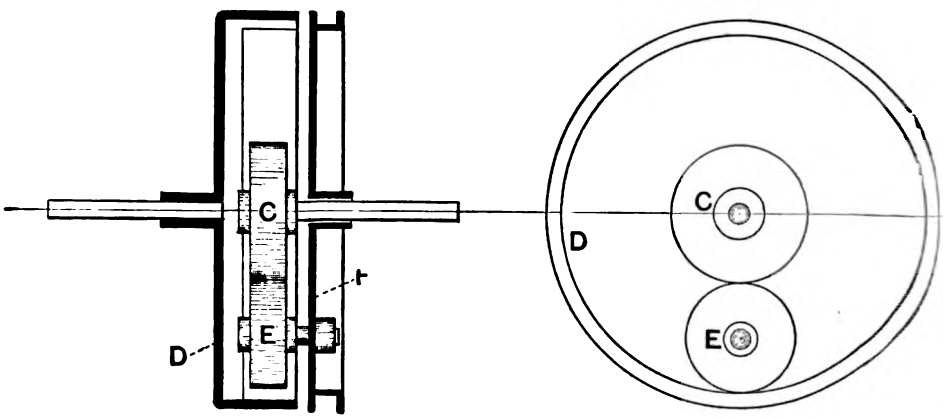

Fig. 6.

pinion *C* is keyed on to the motor spindle, the invert wheel

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D on a shaft geared to the car axle, *E* is a carrier wheel revolving on a stud secured to the disc *F*, which runs loose on the motor spindle.

If the spindle is turned and the disc unrestrained, the carrier wheel will race round the invert wheel; if a brake be applied to the disc and its motion gradually retarded, a proportionate movement will be communicated to the invert wheel. When the disc is held fast the relation of movement between the motor spindle and the axle shaft will be directly as the diameters of *C* and *D*.

The fallacy of this method (not at first discernible) is that the power it is desired to save during starting and for hill climbing is lost in the friction of the brake.

The same law applies to those devices that consist of pumping fluid from one chamber to another. The power is lost in the throttle valve. Their only merit lies in that they permit of rotation of the motor without movement of the car, and allow the load to be gradually applied; but this can be more simply done, if needed at all, by the introduction of a simple friction clutch, as used in my first electric car—an experimental one made to carry six people. The same device was applied to my first full-sized car, but afterwards abandoned as unnecessary. The electric driving of a tramcar involves more than the mere question of the reduction from high to low velocity. The wheels have to drive the car, not the car to take the wheels; it is, therefore, better that the driving power should come from the car. If the motor be fixed to the car, then the multifarious movements due to varying load, springs, curves, uneven roads, stones, &c., all of which disturb the relation between the driving and driven wheel, have to be compensated for.

As illustrative of a gearing that has stood the practical test of five years of successful working, I refer you to fig. 7, which illustrates diagrammatically the gearing used on the cars running at Blackpool.

To the circular frame of the motor is bolted the base of an elbow bracket, *A*, which carries the invert wheel, *W*, gearing into a gun-metal pinion, *M*, on the end of the armature spindle. The box holding the invert wheel has upon its back

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a chain pinion, *P*, from which the power is taken to the large wheel, *C*, keyed upon the axle of the car, which is connected by means of springs, *S*, to the cross arm keyed upon the axle of the car. These springs take up the "snatch" or shock caused on starting the motor, and naturally lengthen the life of the chain. The elbow bracket can be turned upon its base so as either to slacken or tighten the chain at pleasure, without moving the motor or disarranging the centres of the armature pinion and invert wheel. But for the inevitable stretching of the chain and the noise when new, this gear would be all that could be desired. As it is for tramcars whose speed, according to the Board of Trade, must not exceed 9 miles an hour, it is a gear that for efficiency is difficult to beat.

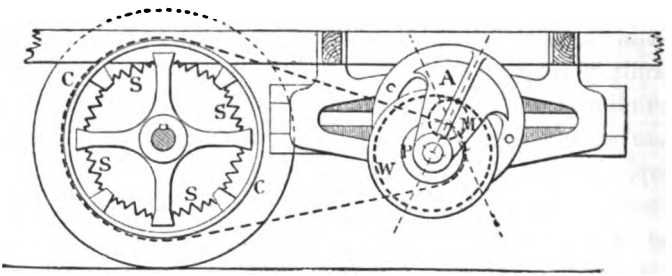

Fig. 7.

In America, where electric traction has been largely adopted, the motors and gearing are usually mounted upon a truck or framework independent of the body of the car. The motors are of the single magnet type, the yoke ends are hinged to the car axles, an intermediate shaft is placed between the armature and the axle, and a set of double-reduction spur wheels are employed to communicate the power from the armature to the axle. An example of this gear was, I believe, employed on the car that ran at the Exhibition here last summer, and it, therefore, is hardly necessary for me to tell you that the excessive noise was very objectionable.

It has been urged that worm gearing is the most convenient for reducing a high velocity to a low one; on the other hand, that the loss in friction is fatal to the economical use of worm gear. The employment of worm gearing is a

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problem for which I believe no reliable data exist or can be formulated; it is a question of compromise, and the difficulty is to strike the happy medium.

The first electric tram or rail car ever run, viz., that made by Mr Thos. Hall of Boston, U.S.A., in 1852, was driven by worm gear; and Mr A. Reckenzaun was *the first* to use it on a full-sized car.

The armature spindle was extended, and carried a worm which engages with a worm wheel keyed direct upon the axle of the car.

The following are the results of Mr Reckenzaun's experiments to test the loss in transmission through worm wheels.

Reckenzaun's Tests of Worm Gear.

Prony Brake A on worm wheel shaft (car axle).
„ „ B on worm shaft (motor spindle).

	Weight on Brake in Kilos.	Revols. per min.	Work on Brake in Kilo-grameters.	Efficiency $\frac{A}{B}$
A,	27	38	4,504·14	·84
B,	4	304	5,338·24	
A,	28	86	10,571·12	·89
B,	4	672	11,800·32	
A,	22	96	9,271·68	·91
B,	3	768	10,114·56	
A,	15	114	7,520·9	·95
B,	2	896	7,881·24	

It will be noticed that the efficiency increases with the speed.

The above figures accord approximately with my own experience.

It must, however, be borne in mind that in the whole range of mechanics there is nothing more difficult to design than worm gearing, particularly for a duty of this kind where the worm has not only to drive the wheel, but when the current is cut off and the car by its velocity continues to move forward, the wheel must drive the worm. No slip clutch can be used with safety. I found it was advisable to intro-

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duce a flexible coupling between the motor and the worm, to give special attention to the thrust block and the lubricating arrangement and the form of thread and tooth.

A drawing of a set suitable for a full-sized tramcar is exhibited.

Let us see how this device lends itself to the problem of dealing with your steep hills and sharp curves; for instance, the top of Leith Walk, in which case all wheels must be drivers.

When the wheels are, as is usual, tightly secured to the axles, then in going round a curve, as both revolve at the same speed, one must overrun the other, causing an additional friction through grinding. This has become so manifest in steam tramcars that frequently one wheel will become so ground as to be an inch less in diameter than the other, increasing materially the coefficient of friction.

It is obvious that this is a question of much more importance, where the wheels have to propel the car, than when the car is drawn along by an outside agency, such as a horse. The recognition of this law is shown in all modern road traction-engines where the wheels are driven by differential gearing. The same remark applies to tricycles.

The problem to be solved then is, How to use each wheel, as a driver, so that each shall do its fair share of work whether on curves or on the straight, when all wheels are new and of uniform size, and when they become irregularly worn.

In fig. 8, A, A represent the axles of a car, with the wheels B, B keyed or shrunk on in the usual manner, and the wheels C, C attached by a long sleeve, whereby they are definitely fixed as to gauge, but free to revolve on the axle. M, M are two motors, each provided with dual armatures, which, with the intervention of flexible couplings, F, operate the steel worms, the worm wheels being keyed B_1, B_2 to the axles, and C_1, C_2 to the sleeves of car wheels C, C.

It is obvious that with this arrangement, when the car is on a straight portion of the line, all the armatures, worms, and wheels are running at the same speed; but as soon as a curve is reached, the free armatures will accommodate the revolution of their respective wheels to the required speed.

A further utility of this arrangement is that the motors

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can be coupled to run in series, multiple parallel, or parallel, and so accommodate themselves to varying loads and speeds, and practically overcoming the before-mentioned difficulty of starting on a steep grade.

So far, we have been considering the employment of electricity as a motive agent on the cars without any reference to how the electric energy itself is to be supplied.

It is of no consequence how skilfully we construct a steam-engine, it won't work without a boiler.

So far back as the year 1839, a Scotchman named Robert

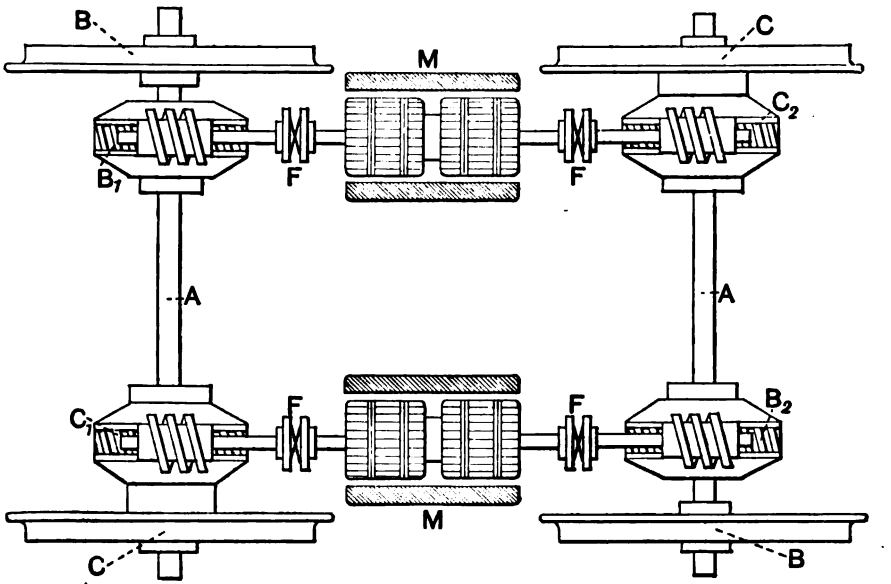

Fig. 8.

Davidson constructed a road vehicle, and actuated it by means of primary batteries.

It is hardly necessary to say that such a source of supply proved too expensive.

A few years ago a notice appeared in the papers that a Frenchman had travelled from Paris with a small box, and conveyed it safely to Glasgow, where a learned professor of deservedly high repute examined it, and astonished the world by stating that it contained stored electricity capable of developing several hundred horse-power if let loose.

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A meaning and importance has been attached to the professor's words which he never could have intended, and from them a delusion has become so fixed in the popular mind that it will be difficult to remove, viz., that electricity can be pumped into a bottle and carried about, and that it is only necessary to turn a tap to obtain unlimited energy.

Let it here be stated that, strictly speaking, there is no such thing as stored electricity, and that the names "accumulators," "storage batteries" are misnomers.

They should be called "secondary" batteries, and their value and utility consists in the fact that, instead of absorbing chemical and mineral elements in the production of electric currents, dynamic force is absorbed,—that is, the power of a steam-engine, water-wheel, &c., and is given out again as electricity.

What takes place may be roughly stated thus:—A battery consisting of metals and acids, preferably lead and dilute sulphuric acid, is taken; the acid has no appreciable effect upon the lead if left alone, but if an electric current is passed through (mark passed through, not made to stop), it so disturbs the acid and the lead that they get angry with each other; the acid divides itself, one element attacks the one lead plate and the other element the other lead plate, and the stronger and the longer the passage of the current, the greater the disturbance. The plates become changed, their natural condition is altered, and remains so after the exciting current ceases to flow; but those plates want to resume their natural condition. Join them with copper wire, they seize the opportunity, and, in making friends again, reproduce electricity.

When the employment of secondary batteries, as a means of power, was brought before the public notice by Faure, Sellon, and various others, with their modification and improvement of the original Planté cell, it was the generally received opinion that the problem of the electrical propulsion of tramways and possibly of railways generally had been solved.

Practical experience, however, has proved this idea to be erroneous, and the principal and leading engineers, both in Europe and in the United States, are fully convinced that, from an economical point of view alone and apart from the

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various physical difficulties, no invention thus far made for the employment of secondary batteries can be called an economic success.

On short roads of one or two miles, with only a very few cars running at intervals of ten to fifteen minutes and with but few passengers, it *might* be still employed; but on roads of any length, where the amount of traffic is great and where twenty or thirty cars must be kept running at say five minutes' interval or even less, and steep grades have to be mounted, no system of secondary batteries can practically be employed. The reasons for these assertions may be briefly stated thus :—

Batteries of sufficient power to drive cars, carrying on an average twenty to thirty passengers, on any other than a perfectly level road, would weigh from two to three tons for each car. The removal and replacing of such batteries, as is admitted by the most sanguine advocates of the system, would be necessary at intervals of from three to four hours, since in that time their power would be exhausted.

The *weight* of these batteries alone would practically represent the carrying of on an average thirty persons each car, making a most important factor in the estimate of cost of the system. To this must be added the considerable expense of the number of men necessarily employed in the constant changing of these heavy weights, and also the fact that the cars must remain idle whilst this changing is going on, which necessarily involves a large increase in the number of cars above what the traffic would absolutely require if such delays could be dispensed with.

In the by no means impossible event of a short circuit occurring in the connecting wires of any of these powerful batteries, there is a very great danger, even probability, of the car being set on fire.

The necessary machinery to charge these batteries, their original cost, the keeping them in repair, and the number of hands required, necessitate an expense so great that it would be quite impossible to run say thirty cars daily on a tramway of five miles' length, with a five minutes service, at anything like the same total cost and yearly expense as would be

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sufficient to lay down and maintain a permanent direct driving line.

On this point there is, in the minds of the best informed electrical engineers, no longer the slightest doubt, the opinion being justified by the results of practice. This is to be regretted, for the employment of batteries naturally suggests itself first, and is the more taking method. Each car is a distinct unit; it can be run on any line, can follow after horses or steam-engines. Where the rails are it can go, no special preparation of road being necessary. That this can be done has been sufficiently demonstrated to leave no manner of doubt as to the fact. Then why are they not more employed? For the simple and sufficient reason that they cost too much. If batteries could be shown to pay, the minor questions of risk of fire from short circuiting, the unpleasant odour, the damage from spilt acid, and the danger to wheels and road from the excessive weight might all be overcome.

Everybody wants the battery to succeed, and, notwithstanding the enormous amount of money that has already been spent in fruitless efforts, funds are still forthcoming to continue the experiments; but, until a battery altogether different from any existing one and at present unknown to electric science has been evolved, tramcar propulsion by means of batteries cannot compete with horses.

No better example than Brussels could be given of the failure attending the employment of secondary batteries, for a more thoroughly worked-out installation is not likely to occur. No expense was spared in the first outlay, the experiments were continued with praiseworthy perseverance, and yet the working had to be abandoned; for, quoting the reported words of the chairman, "it failed commercially on every point."

The remarks respecting the employment of secondary batteries in the car itself are applicable with greater force to the employment of a separate electric locomotive charged with batteries.

I have dwelt, perhaps, too long on this part of the subject. My reason for doing so is that the real progress of electric traction in this country has been, in my opinion, materially

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hindered by the public credulity in the possibility of tramcar traction by batteries.

Let me repeat, cars can be driven, and well driven, by batteries, and when so driven are better than horses or steam.

But tramway companies are not philanthropic or charitable institutions, and neither to save the horse nor please the public, can they be expected to adopt a system that costs more than their present methods.

The only argument for batteries is, that by using them instead of horses a considerable increase in the traffic may ensue; and if the receipts per car mile increase, say 40 per cent., the company can afford 20 per cent. more for traction. The value of such reasoning needs little comment.

Direct Driving.

At present the only economic way for electric haulage is by direct current, and the problem is, when the electricity is generated at a fixed station, to so distribute it throughout the tramway route that the cars can gather and use it as they pass along. If the cars were running upon a track reserved exclusively for their use, the work would be simple; but in streets other vehicular traffic has to be considered, and not only have numerous Board of Trade conditions to be complied with, but local authorities and householders have also to be consulted and satisfied.

The public safety is of paramount importance; no system must be permitted that endangers human life.

The public taste has also to be considered, but taste is often confused with prejudice, and that is a difficult material to cope with.

All system of direct driving applicable to the public streets may be classified under two heads—Overhead Wires, or Underground Conductors.

Overhead Conductors.

It is generally admitted that the cheapest and simplest method of supplying electric energy to street tramcars is by means of overhead conductors, and assuming that their

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employment is sanctioned by the road authorities, it becomes necessary to consider what kinds of overhead conductors are admissible, having regard to efficiency, public safety, and appearance. The first point to decide is an electric one, viz., whether the overhead wire shall only supply the current to the cars, return being made by the rails, or whether both the flow and return wires shall be carried overhead. Both systems have been tried, and much can be said in favour of each. The first is generally favoured, and has been largely adopted. The chief objection to the second is the great difficulty that arises when points and crossings have to be dealt with, and the additional expense; but for these points, which are of practical importance, it is electrically the better method.

When the overhead conductor only conveys the current to the cars, and the return is made by the rails, three plans may be adopted, viz., a plain wire may be used, the current being gathered from it by a slider or contact-maker running or sliding upon the wire, connection being made with the cars by a flexible insulated wire. When this is adopted, the overhead wire must be strong enough to bear the weight of the gatherer and the downward pull of the cord. Special care is necessary in attaching the wire to the insulated support, for its diameter must nowhere be increased, or the slider would not freely pass. A great advantage of this method is that the overhead conductor wire need not be over the centre of the rail track; considerable deviation may be safely permitted.

The second plan is similar to the first, but with the insulated supports inverted, the conductor wire hanging below them, and instead of a slipper sliding on the top, a rubber rolling or brushing against the under side is employed. It is obvious that the wire giving no support to the "rubber," it must be held against it by a definite force, and for this purpose what may be termed a fishing-rod is attached by a spring to the roof of the car, but retained by a cord which regulates its pressure against the overhanging wire. By this method no downward strain is put upon the wire, but it must be approximately over the centre of the car.

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The third plan, instead of a wire, a metal tube is employed with a slit in the under side for the passage of a thin plate, attached to a shuttle which slides within the tube. Connection is made with the car by a flexible cord, as in the first plan. The advantages of this method are that there is no risk of the gatherer falling off, that it is out of sight, and there is less risk of sparking or flashing than in either of the other plans. Its disadvantages are increased cost, and a seven-eighths of an inch tube instead of a three-eighths wire.

The Moedling-Hinterbruehl line may be taken as typical of this class. M. Reckenzaun, in his paper before the Society of Arts, London, in 1887, gives the following description of it:—

"The conductors are made of slotted tubes in lengths of 15 feet each, and soldered together when placed in position. To prevent them from sagging stout wires are stretched over brackets on the tops of posts, and fastened to the tubes half way between the posts. The bore has to be made perfectly smooth and clean, so that neither mechanical nor electrical resistance is offered to the contact carriage sliding within; the actual diameters of the tube are 1 inch internally and 1⅛ inches externally. The contact carriage consists of a flexible piece of flat steel upon which three gun-metal pistons are fastened; these pistons, which have to be renewed every two months, are made in two halves, with springs in the middle, whereby a slight pressure is produced between the surfaces in contact.

"The Moedling-Hinterbruehl tramway has been working successfully since 1884, at an average cost of 3·42d. per car mile, inclusive of every item of expense."

Separate special supports must be used for carrying the overhead conductors, for stringing cross wires from windows to house walls, from chimney-tops to lamp-posts, cannot be considered as permissible. When the streets are wide, forming broad avenues, with the tramway in the centre, leaving sufficient room for other carriages to pass each other between the tram-rail and the kerbstone, and the space occupied by the tram-rails is used almost exclusively by the cars, then, and only then, the best place for the poles or standards is in the centre of the road, between the two sets of rails, each

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standard having an arm stretching right and left, and supporting a wire over the centre of either track. This is the very best arrangement where the width of street will permit it; but it is obvious that in ordinary streets the presence of a pole in the centre of the roadway every forty yards would be a serious hindrance to other traffic, and a prolific source of danger.

The safest place for the standards is on the kerbstone, and where the "slipper" or "shuttle" with the flexible cord are used, a short arm extending a few feet from the footpath is sufficient for supporting the wire or tube; but when the rubber and fishing-rod are employed, requiring the wire to be over the centre of the track, it is necessary to have the standards higher, and stretch wires across the street, hanging the electric conductor from them in the centre of the track; this produces a network of wire, and forms one of the objections against the system.

By the courtesy of a friend I am able to show you several photographs of overhead wire lines in America; he has also furnished me with the following statements, illustrative of the marvellously rapid progress made in that country.

Statement of American Electric Tramways.

On January 1, 1886, there were in the U.S.A., three experimental electric lines, aggregating 7½ miles' track and 13 cars.

March 1891, there are 319 electric tramways in operation in 204 cities, and aggregating 2371 track miles and 3747 motor cars.

The largest equipments are West End Street Railway Company, Boston, 350 double motor cars, 65 miles of track equipped. This is to be extended to 230 miles, and power stations to contain the steam-engines and boilers for driving the generating dynamos to operate 1300 motor cars are now being constructed. Shareholders have authorized an expenditure of over £1,000,000.

Minneapolis and St Paul Street Railway has 100 electric cars in daily operation, and 100 more contracted for,—contract price £400,000.

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Cleveland, Ohio, and St Louis, Missouri, have each 100 electric cars in daily operation.

Dynamos and motors representing 200,000 horse-power have already been sold for electric tramway work.

Statement of comparative test made in St Louis (ending Dec. 17, 1890) upon a cable and an electric line in that city operating under approximately the same conditions:—

	Cable.	Electric.
Length of round trip, miles	9·64	12·22
No. of days compared	198	198
Cost of power, including labour, fuel, oil, grease, tar, waste, and repair,	$29,957·72	$26,687·88
No. of regular trains per day	20	25
Total round trips	61,380	82,630
,, passengers carried	2,928,918	3,032,425
,, time per round trip, minutes	72	96
Stops at terminal, minutes	8	19
Actual running time per round trip, minutes	64	77
Mean running speed, miles per hour	9·038	9·522
Cost per trip, cents	48·8	32·3
,, of power per train mile, cents	5·06	2·72
,, of power per passenger carrier, cent	1·023	0·88
Allowing each passenger a ½ round trip, cost per passenger per mile, cent	0·424	0·29

Though not for a moment wishing to see our streets disfigured by the rough and ready clumsy work too often permitted in the States, I can but express a hope that English prejudice will soon give way to utility and permit the use of some overhead system, regard, of course, being had to substantial work and neatness, if not elegance of design.

I venture to submit a design of a supporting standard for your criticism and, I hope, approval.

In the busiest thoroughfares of our large towns permission to erect overhead wires for tramcar traction can hardly be expected, and recourse must be had to underground conductors.

Underground Conductors.

As far back as 1852, Mr Thomas Hall, of Boston, U.S.A., constructed a model of an electric car, using the rails as conductors, one conveying the current to the car, the other

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returning it to the stationary battery. This may be described as the "come rail, go rail system," but attempts to employ it for street tramways have proved failures, because the rails, being electric conductors, were dangerous to the public, especially to horses with their iron shoes; and the rails being embedded in the earth, the electric leakage was so great as to make it practically inoperative for long distances.

As safety to the public is of first importance, the electric conductors must be out of harm's way, and to secure this an underground conduit is necessary, running the length of the line.

The conduits may be classified as closed and open.

The advantage of the closed conduit is that it dispenses with the slit in the surface of the road; many devices have been patented for this purpose, in all of them temporary communication is made between the electric conductor within the conduit and the section of the surface that lies immediately beneath the car.

This communication may be effected either by a little motor trolley running within the conduit—by mechanically or electrically actuating switches, or by magnetically attracting a strip or spiral that normally rests upon the enclosed conductors, but is raised to the surface as the car passes.

No tramways have yet been constructed with a closed conduit.

The largest demonstration hitherto made was in Paris, during the Railway Exhibition in 1887, when one of my patented systems was used and worked successfully, carrying a great number of passengers. I have pleasure in showing you a photograph of the car.

Open Conduits.—Many suggestions and experiments have been made for the employment of open conduits or channels with a slit or opening in the surface, but the first complete tramway made, viz., that at Blackpool in Lancashire, is the only successful one.

Before the construction of the Blackpool Electric Tramway many progressive experiments were made. They have been described and published in the technical papers, so it is unnecessary for me to refer to them at any length this

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evening; but you will find upon the walls illustrations of the pleasure car and track employed at Moorside, Halifax, and of the full-sized car that ran in a field near Manchester. The Moorside track is illustrated in fig. 9 and the Manchester track in fig. 10.

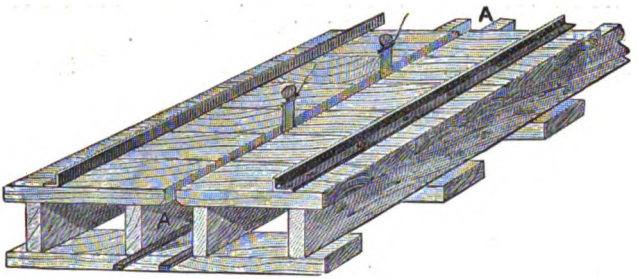

Fig. 9.

As previously stated, the first electric tramway constructed having a channel with a slit or opening in its surface is that at Blackpool in Lancashire. It is the only successful one in existence.

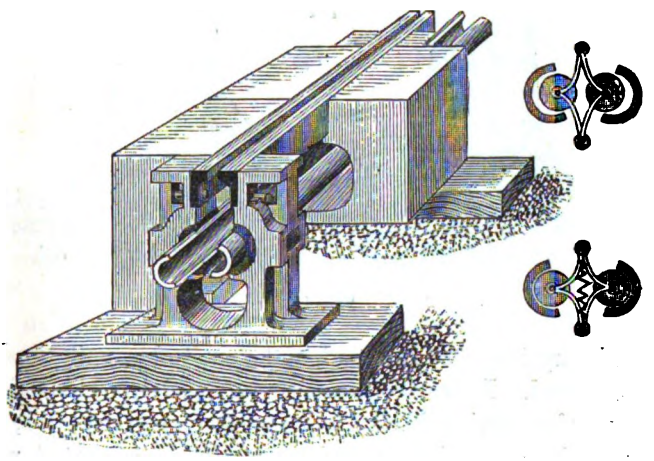

Fig. 10.

The Blackpool Electric Tramway.

The tramway is 2 miles in length and runs the length of the Esplanade.

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During the season eight cars, seating on an average 45 passengers each, are constantly at work.

The electricity is generated at a central station and conveyed to the cars by means of an underground channel in the centre of the track, having a narrow slit or opening in its surface for communication between the electric motor on the car and electric conductors within the channel.

The channel (fig. 11) is formed strong enough to support

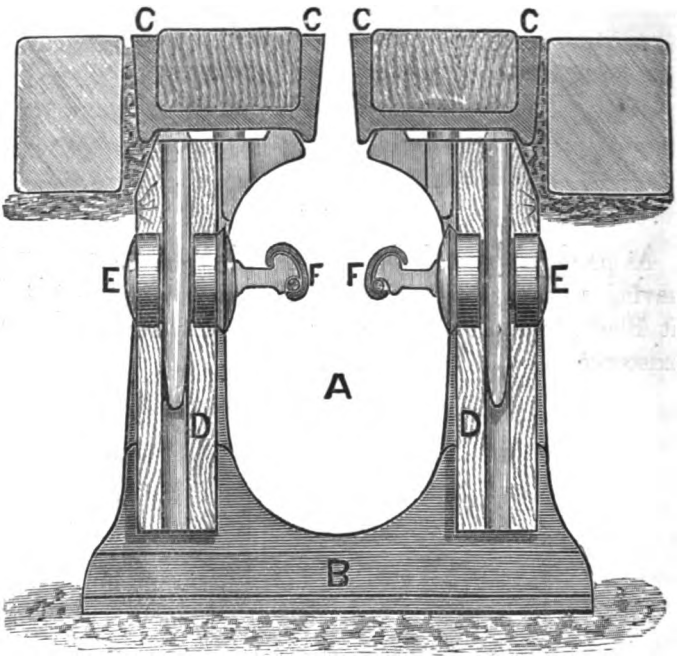

Fig. 11.

the ordinary traffic of the road, and so as to be easily flushed and cleansed. Its surface consists of steel troughing filled with wooden paving blocks, and forms a good roadway; the sides of the channel are partially formed of creosoted wood holding porcelain insulators, which carry electric conductors of special drawn copper, so formed that they can be readily and securely fixed, and the different lengths secured by expansion joints.

Two conductors are supplied,—first, that they may be hidden

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under either side of the surface, and so be protected from injury by any substance falling through the slit in the surface of the channel; and, secondly, to make it possible to deal with points, loops, and crossings. Only the positive electricity passes along these conductors; the return is made by means of the rails, which are electrically connected one with the other.

Communication is made with the cars by means of a collector, which runs upon the copper conductors within the channel. Insulated copper bands, protected by steel plates, pass through the slit or opening in the surface of the road and by a flexible insulated cord attached to an electrical terminal underneath the car, so that when the car moves, the collector is drawn along with sufficient force to clean away any ordinary obstruction; but should an absolute block occur, then a special clip releases the collector, and a breakage is avoided.

From the terminal underneath the car, the current passes to the switch-box, where the quantity and direction of the electricity to and within the motor is regulated, and thereby the speed and direction of the car is controlled.

Switch-boxes are placed at each end of the car, and are provided with removable handles, without which it is impossible to operate them. The driver, who has charge of these handles, can cause the car to move backwards or forwards at will. From the switches the current goes to the motor, and there produces mechanical energy. The motor, running at a high speed, a combination of spur and chain gear is employed to communicate the power to the wheels and drive the car. The gear is specially designed to run smoothly and silently; from the motor the current passes by way of adjustable clips to the axles, and by them through the wheels to the rails and back to the station, where the electricity is generated.

The engines and dynamos are in duplicate, and so made that they produce just the amount of electric energy required, so that, if no car be running, no work is expended; if one car, just enough to drive one, and no more; if ten cars, sufficient for them, and so on up to the full capacity of the

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machines, which are constructed to the requirements of the line.

The generators fixed at the engine-shed are capable of driving ten loaded cars—sufficient to carry 400 passengers.

As an example of the capacity for carrying exceptional traffic with a very small increase in the working expenses, the following statements may be of interest.

On the line at Blackpool the number of passengers carried during a week of six days in the winter was 2393, at a cost, for fuel and wages, under £24. During the week ending September 4, 1886, which was in the height of the season, the number of passengers carried was 44,306, while the cost of wages and fuel was only £45.

Blackpool, being a seaside holiday resort, crowded in the summer and deserted in the winter, the traffic is essentially a season one. The following analysis of the cost of working may be interesting:—

	March.	August.
Passengers carried, per week	2,714	42,933
Miles run, ,,	813	2,649
Receipts, ,,	£21 15 4	£334 10 8
Cost of coal, ,,	3 15 1	4 19 6
Total expenses, ,,	21 9 9	45 1 6
Average miles per car, per day	45	52
Cost of coal, per car mile	1·1d.	0·45d.
Total working expenses, per car mile	6·3d.	4d.
Expenses, per passenger	1·8d.	0·25d.

Let me now point out some defects in the Blackpool arrangements.

Notwithstanding the provision for expansion and contraction of the copper conductors, through varying temperature the sliding points oxidize fast, cease to work, and buckling of the conductor tubes follows as a consequence.

Unless careful attention is given to keeping the channel clean, dirt will lodge upon and rest between the tubes and their insulating supports, causing leakage of current.

If an insulator gives way, the adjacent set, or paving stone, in the surface of the road has to be dug up before the insulator can be renewed.

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All these points are fully met in the design I now submit, where it will be seen, instead of a rigid tube acting as conductor, flexible rods or wire cords are suspended from the roof of the channel. By this device the number of insulators, which are each a cause of weakness, can be reduced 75 per cent.; and if any one fails, it can be easily renewed by lifting the covering cap.

It is not absolutely necessary that the channel be placed midway between the rails, though that is the position much to be preferred. It can be placed alongside, or form part of one or both rails. A practical method of accomplishing this is shown in the drawing upon the table.

It would be interesting, if time permitted, to give a *resumé* of the various details that have been and are being continually produced for underground channels, but that it is impossible to do this evening.

I have confined my attention to electric traction for tramways, but for the information of those who like to examine them, I have brought a set of drawings showing the plans, prepared in conjunction with the late Mr J. F. La Trobe Bateman, for working the City and Southwark Railway by electricity.

In conclusion, it may be stated that—

Batteries are the most attractive, but are expensive and troublesome, and can't be made to pay.

Overhead lines are the simplest and cheapest, but are objected to on account of their appearance and attendant risk.

Underground channels are more expensive to construct than overhead conductors, but less costly than batteries, and when properly constructed are the best, safest, and most reliable.

In large towns the busy thoroughfares should be equipped with underground channels, and the suburban districts with overhead lines. Where efficient systems are employed, the change from one to the other is readily made.

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Address by the President, ALEXANDER LESLIE, M. Inst. C.E., F.R.S.E., F.G.S., *delivered at the Annual General Meeting of the Society held on* 14*th November* 1892.

As I conceive that it will not be considered unnatural in me to select an engineering subject for my address to-night, I propose to give a short description of four of the largest water-works in this country, which, I hope, may be of some interest to you. Although the time at my disposal this evening is too limited to permit of my giving more than a general outline of them, it will yet be sufficient to enable you to make a comparison as to their relative magnitude and expense. I have selected for consideration the water-supplies of Glasgow, Liverpool, Manchester, and Birmingham, and I shall deal with them in their chronological order.

I purposely omit any allusion to the water-supply of London, as it, although as a whole vastly greater in quantity than that of any of the places mentioned, is made up of a number of small supplies, belonging to different companies, none of which individually presents any special call for reference at the present time.

Glasgow, as most of you are doubtless aware, derives its supply for the most part from the Loch Katrine watershed. This scheme, the main feature of which consists in the adoption of tunnels for conveying the water through the intervening range of hills, was originally propounded by some Glasgow engineers, and was carried out ultimately under the superintendence of the late Mr Bateman of London.

The Glasgow Corporation applied to Parliament in the session of 1853–54 for a Bill to introduce water

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from this source, but, owing to opposition by the Admiralty, who were apprehensive that damage to the navigation in the estuary of the Forth would be caused by the abstraction of the water for Glasgow, the Bill was rejected. This was, however, followed the next session by another application, which this time was successful. The works were commenced in the beginning of 1856, and formally opened by Her Majesty the Queen in the end of 1859.

The main feature of this scheme, as I already remarked, was the piercing of the range of hills lying to the south of Loch Katrine by means of a series of tunnels, thus shortening the line of aqueduct necessary to bring Loch Katrine water into Glasgow, an engineering expedient which, previously to this, had not been adopted on a similar scale.

The total drainage area operated upon down to Loch Vennachar sluices is 48,000 acres, of which 23,000 acres drain into Loch Katrine, from which the supply for Glasgow is obtained, the remaining area being utilised for providing compensation water to the river Teith, a tributary of the Forth.

By the Loch Katrine Act of 1855, the storage necessary for securing a daily supply of 50 million gallons was obtained by providing a rise and fall on the surface of Loch Katrine of 7 feet; that is to say, power was taken to raise the level 4 feet by the formation of an embankment across its outlet, and to lower it 3 by means of the before-mentioned tunnel.

The tunnels, through which the water is conveyed under the ridge of high land to the south of the Loch, were expected to be capable of carrying 50 million gallons per day, but experience showed that in consequence of the friction caused by the rough rock sides

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of the aqueduct, the velocity was so much diminished that not more than 40 million gallons per day could be delivered by them.

This supply from Loch Katrine was ample for all the requirements of Glasgow for many years, but it ultimately became obvious that steps must be taken to provide means for obtaining an increased delivery of water to this community.

It therefore became necessary, in order to provide for the increasing wants of Glasgow and the surrounding district, which is now included in the area of supply, to construct an additional line of aqueduct, consisting this time chiefly of tunnels, and also to provide additional storage in Loch Katrine by raising the level of the overflow 5 feet; and when these works which are now in progress are completed, including the utilisation of an additional area of 3100 acres now draining into Loch Arklet, there will be available for Glasgow from this district a total supply of 75 million gallons per day.

The new aqueduct is intended to carry 70 million gallons, making, together with the existing one, a total of 110 millions per day, of which 100 millions will be available for Glasgow. The additional 25 millions will ultimately be obtained from the watershed of the river Leny, which can be diverted from its natural course into Loch Katrine.

The consumption of water in Glasgow has, for the last 25 years, been about 50 gallons per head per day, of which about 17 gallons are used for manufacturing and sanitary purposes. The population requiring to be supplied, when the original works were executed, was less than one-half of what it is at present.

The original scheme cost £1,500,000, and the cost

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of the extension works is estimated to cost £1,000,000 additional.

The work necessary to provide sufficient storage was, under this scheme, very simple, and involved the construction of small embankments, as the large area of the natural lochs operated upon, both for town supply and compensation, rendered unnecessary the construction of impounding embankments of such magnitude as have been required elsewhere.

The works for conveying the water to Glasgow consist of many miles of tunnel through hard rock, and also culverts, such as are now termed *cut and cover;* and at the crossings of the various valleys met with in the course of the aqueduct, high bridges carrying wrought-iron troughs were employed, and, where suitable, cast-iron inverted syphon pipes were made use of. The original supply of 40 or 50 thousand gallons required three lines of pipes in these syphons, two being of 48-inch and one of 42-inch diameter, and the whole scheme for 100 millions when completed will require an addition of four lines of 48 inches diameter.

The original works were constructed under the personal supervision of Mr Jas. M. Gale, the well-known engineer of the Glasgow Corporation Works, and of Mr G. H. Hill, C.E., and Mr Alfred Moore, C.E., now of Manchester.

The extension works now being carried out include the construction of an additional service reservoir at Craigmaddie, which is situated alongside the original one at Mugdock, and will be capable of containing 700 million gallons. These two service reservoirs form a store from which to draw the daily supply whenever it may be necessary to shut off the water in the main aqueduct for inspection or repair. The most important

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feature in this reservoir is the puddle trench, which it has been found necessary to excavate through hard rock to an ultimate depth of 200 feet at some portions of it, so as to reach a water-tight foundation, but this has lately been satisfactorily accomplished, and it is now being filled with clay puddle, of which a plentiful supply has been obtained conveniently near to the site of the works.

I have prepared a diagram and an explanatory table (see page 304) which shows, for the sake of comparison, the various points of importance in connection with the different water-works which I am bringing before you.

The next place to which I shall refer is Liverpool.

The present population within the city boundaries is 518,000, while an additional 300,000 are comprised within the area of distribution now supplied by the Corporation of Liverpool.

This city originally obtained its supply from extensive wells sunk in the new red sandstone formation, but the water-works required to be enlarged on another plan when these wells began to fail, which they were found to do both as regards quantity and quality, as experience has shown that wells similarly situated are likely, after long use, to produce water of inferior quality, caused, as in this case, probably by the infiltration of salt water from the adjacent sea induced by continued pumping.

Mr Hawksley recommended a scheme, which was called the Rivington Pike, the water of which was to be obtained from a district in Lancashire, distant about 35 miles, and capable of yielding a daily supply of about 20 million gallons. This scheme, like most others, met with considerable opposition, and Mr

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Hawksley himself has described to me how he was caricatured in one of the local pantomimes written by the well-known Mr Tom Taylor, and was represented on the stage as a large pike opening and shutting its mouth. It was, however, successfully carried out, and, along with an extension of the original pumping scheme, served the city, although ultimately with difficulty, till the recent introduction of the water from Wales.

When this supply in its turn came to be exhausted, or, to express it more accurately, was fully utilised, during which various schemes were under consideration, including supplies from the English lakes, &c., and after considerable delay, it was ultimately decided to obtain an additional supply from a suitable watershed in Wales, and a scheme was laid out by Mr Thomas Hawksley, C.E., the most experienced water-engineer of the age, and Mr Deacon of waste water-meter fame, for the purpose of utilising the water of the river Vrynwy, a tributary of the Severn, in the County of Montgomery in the north of Wales.

The character of these works differs very materially from those of Glasgow previously described, and the following are some of their particular features.

The drainage area utilised or operated on amounts to 18,000 acres, while an additional area of 5200 acres adjacent to it can be appropriated when necessary. The scheme is calculated to provide a daily supply of 40 million gallons, and for this purpose a large reservoir, named Lake Vrynwy, has been constructed on the stream, $4\frac{3}{4}$ miles in length and about $\frac{1}{2}$ mile in breadth. This reservoir has a capacity of 12,000 million gallons, and the greatest depth is 84 feet. The configuration of the valley is peculiarly suitable for the construction

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of such a reservoir, as the gradient on the stream flowing through it is remarkably flat at this portion of its course, while the sides rise quickly out of an extensive plain. The surface of the reservoir is 1121 acres in extent, or nearly three times the size of the Gladhouse Reservoir of the Edinburgh Water-works, and its capacity is seven times as great.

The dam by which the water is impounded is 1172 feet in length, and the greatest height from the foundation to the parapet of the carriage-way, which is led along the top of the dam on arches, is 161 feet.

The surplus water of floods finds an exit over the top of the dam along nearly its whole length. The greatest thickness of the dam at the base is 120 feet. The batter on the water face of the dam is about 1 in 7, and the slope at the back is about 1 in $1\frac{1}{2}$. The length of aqueduct from Vrynwy to the service reservoirs at Prescott is 68 miles, and it is 9 miles further to the centre of the town of Liverpool.

The aqueducts and tunnels in connection with this scheme have been constructed of sufficient size to carry the whole water which is expected to be obtained from this source, viz., 40 million gallons per day, but the first instalment will only provide 13 millions, so that only one out of the intended three cast-iron pipes has been laid, the other two to be provided as shall be required.

The total cost of the scheme, including the purchase of land, is about £2,100,000.

The works were commenced in 1881, but it was not until a few months ago that the water of the first instalment was introduced into Liverpool, showing that about eleven years were necessary in order to execute the works.

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When the Vrynwy Works were undertaken, it was expected that they would be completed five or six years ago, and as the population and trade demands continued to increase, considerable difficulty was experienced in giving a satisfactory supply to the district, especially during the extreme droughts of the years 1885 and 1887.

As a temporary provision to meet the deficiency pending the completion of the new works, several works for the purpose of obtaining temporary supplies had to be undertaken, chiefly—

(1) A supply of salt water from the river Mersey for public swimming baths, street watering, and sewer flushing, and

(2) The enlarging and deepening of bore-holes in the public wells.

In addition to the water thus obtained, arrangements had to be made one year for a temporary supply from an adjoining Local Authority which had been allowed to sink a well within the Liverpool district, and whose delivery main passed one of the Liverpool reservoirs.

The dam which forms the Vrynwy reservoir was one of the first in this country which was constructed of masonry instead of earthwork, as had formerly been the custom, and the reason for selecting this material was that the geological structure of the valley, viz., the Lower Silurian, while it rendered it difficult, if not impracticable, to obtain material suitable for forming an earthen dam in sufficient quantities, afforded abundance of suitable building stone for the purpose of erecting a dam of masonry.

The section of the dam shows a particularly solid structure, and is immensely more suggestive of stability than any which had hitherto been constructed of this

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kind. Reference to the cross sectional area of the famous Furrens Dam will show at once the wide margin of safety which has been adopted in the design of the Vrynwy Dam. There were certain differences of opinion expressed as to the quality and sufficiency of the style of workmanship employed, but it is unnecessary to allude further to this on the present occasion.

As a matter of course, a certain amount of compensation water was awarded to the Vrynwy River, which is a tributary of the Severn, and there is little doubt that it will profit to a very considerable extent during dry weather by the compensation which has been awarded to it.

The arrangements in regard to this compensation differ somewhat from those generally in vogue, as it is stipulated that while not less than 10 million gallons of compensation water shall at all times be discharged from the reservoir, this amount shall be increased to 50 million gallons per day for thirty-two days between the months of March and October. The 10 millions itself is more than $3\frac{1}{2}$ times the minimum flow, therefore the parties interested, viz., the Severn Commissioners, have made a satisfactory bargain in this respect.

There are several important works on the line of aqueduct between Lake Vrynwy and Liverpool, the chief of which consists of a large regulating reservoir and filter-beds; and at various places along the line of the cast-iron pipes, which vary from 39 inches to 42 inches, according to their gradient, there are balancing reservoirs so placed along the gradient line as to have the effect of taking off undue pressure from the pipes, which might otherwise injure them without interfering with their calculated delivery.

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An elegant structure has been erected at Norton for the purpose of forming a balancing reservoir of this nature, where the level of the ground is not sufficiently high to allow it to be constructed by excavating and embanking on the solid ground in the ordinary way. It consists of a tower about 120 feet high, built of masonry in the Roman Doric style, and it is surmounted by a circular tank of wrought iron.

One of the chief engineering difficulties in connection with this scheme was the crossing of the rivers Mersey and Weaver, and very special works were required in order to achieve this.

There are many other interesting details in connection with this scheme, but these cannot at present be alluded to.

The next work to which I shall refer is the Thirlmere scheme for the supply of Manchester.

Until about twenty years ago, the Manchester waterworks had been constructed and added to in instalments, when the original scheme may be said to have been completed, by means of which the drainage area of the Longdendale Valley, amounting to 19,300 acres, has been bit by bit utilised, a long series of reservoirs at varying levels having been built across the river Etherow, having together a total area of 854 acres and a capacity of about 6,000 million gallons.

The supply available for the Manchester district from this source is about 25 million gallons per day, and compensation to the stream is given amounting to 13½ millions.

About the year 1877 the Corporation, on the advice of their engineer, Mr Bateman, resolved to apply to Parliament for power to appropriate Thirlmere Lake and the adjoining drainage area as an extension of

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their supply; and here, as at Liverpool, they seem to have suffered from the delay which occurred in deciding on and in obtaining from Parliament the powers necessary for commencing the works for the introduction of their new supply. Their first application to Parliament was thrown out, and two years were allowed to elapse before the scheme was ultimately authorised.

The Act was finally obtained in 1879, but the works were not commenced till January 1886.

These works consist of the adaptation of Thirlmere Lake as a reservoir, and this is achieved by the construction of two masonry dams at the natural outlet at the north end of the lake, while the water is taken to Manchester by an aqueduct about 96 miles long, commencing at the south or upper end of the lake.

Thirlmere Lake is situated in Cumberland about 5 miles south of the town of Keswick. The lake was originally about $2\frac{3}{4}$ miles in length, and the geological structure of its drainage area is very similar to that of the Vrynwy Lake, consisting of lower silurian rocks.

The rainfall here is excessive, and, in fact, it is probably greater than is to be found anywhere else in this country. Some portions of the drainage area have as much as 137 inches in the year.

The total area worked upon by this scheme is by no means very large, amounting in all to about 11,000 acres, but the extraordinary amount of rainfall renders it possible to obtain from it a very much larger daily supply than can be expected in any other part of the country.

The storage is obtained by raising the level of the lake 51 feet, whereby its area will be increased from 328 to 793 acres, and an available capacity of over 8,000 million gallons will be got; and,

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after deducting compensation to the river, it is estimated that 50 million gallons per day will be available for town supply in addition to the 25 millions obtainable from the present sources.

The masonry of the dam is not unlike that of the Vrynwy Dam already alluded to, but there is this difference in the design of the works, that whereas the outlet works for the compensation water were formed through the masonry of the dam at Lake Vrynwy, they are here made on an entirely different line, as they consist of a separate tunnel and relative sluice shaft; and, while at Vrynwy the overflow water of the reservoir is allowed to pass over the top of the dam underneath the carriage road, at Thirlmere there is a special waste weir formed in the solid ground by which the surplus or flood waters are allowed to pass into the bed of the stream.

The aqueduct carrying the water to Manchester consists of many miles of tunnels, cut through the solid rock; in some places requiring protection, which is obtained by concrete lining, and in other places the rock is sufficiently durable to stand without anything but its own surface in contact with the water.

It is ultimately intended to have five lines of piping, and arrangements have been made in purchasing the land to allow of the additional pipes being put in according as they may be required, but for the first instalment only one line of 42-inch pipes is being laid.

There are numerous interesting and important pieces of work to be found on the line of the aqueduct, consisting of bridges, straining wells, &c., and it may be interesting to notice that the sluices at the outlet of the lake at the beginning of the aqueduct are designed in duplicate, and that one of them is to be worked by

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hydraulic pressure obtained from the water of a neighbouring brook, while the other is fitted up with hand gearing.

It is expected that the whole work will be completed in about one year from this time, and Manchester will then be in a much more comfortable condition with its efficient water-supply than it has been in the straitened circumstances which have existed for the several years past.

The water-supply of Manchester, which had for some time been delivered as is now done in Edinburgh on the constant service system, has necessarily from time to time been restricted so as to be what is known as intermittent. Under certain circumstances this restriction cannot be considered any very great privation, provided there is sufficient cistern accommodation to enable a household to get along during the time the mains in the street are empty, and provided there are no such luxuries as high-pressure boilers, hot baths, &c., which elsewhere are considered a *sine quâ non*. But one can easily imagine the amount of confusion and discomfort, not to mention actual danger, which would result from intermittent services in a town such as our own, containing highly-rented houses, and where probably 50 per cent. of the properties in it are provided with high-pressure boilers, if the water had to be shut off during some portion of every day, as the first thing to be done under these circumstances is to extinguish the kitchen fire, so as to avoid risk of boiler explosions, and those who have ever experienced this discipline can best appreciate it.

The fourth and last place to which I shall allude is Birmingham.

The water-supply for Birmingham was originally in

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the hands of a company, and the works were taken over by the Corporation in 1875.

The population is upwards of 600,000, and the district supplied varies in elevation from 290 to 600 feet ordnance, this of itself causing considerable difficulty in the satisfactory distribution of the water-supply.

The original supply for Birmingham was derived partly from impounded surface water and partly from wells sunk as at Liverpool in the new red sandstone, and the supply now available is about 16½ million gallons per day, or about 27 gallons per head per day. Of this quantity about 9 gallons are used for trade purposes, leaving for purely domestic and sanitary purposes 18 gallons. It may be here mentioned as a comparison that in London the domestic consumption is about 25 gallons per head, but this must be taken as no criterion of what is or ought to be a sufficient supply for places elsewhere, as the consumption per head depends entirely upon the habits of the people, which certainly vary greatly in different places. I may here point out that when, as frequently occurs, comparisons are made between the daily consumption per head in different towns throughout this country, the real reasons why the inhabitants of one town consume much more than those of another are entirely overlooked; and before any accurate estimate of what the legitimate quantity to be used can be arrived at, proper information as to the habits of the consumers, and the nature of the sanitary appliances in use, must be obtained.

So long ago as 1871, steps were taken to obtain advice as to an additional supply, and Mr (now Sir) Robert Rawlinson was instructed to report on this

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subject, while Mr Mansergh, the present engineer, was employed to assist him in the investigation. Nothing, however, was done at that time beyond the recommendation of Mr Rawlinson to appropriate the water of the Elan and Claerwen Rivers as a suitable source for Birmingham, and in 1890 Mr Mansergh was instructed to submit a scheme suitable for the requirements of the district.

Mr Mansergh recommended the scheme in the survey of which he had been formerly engaged, which consists of the utilisation of an area of 45,562 acres drained by the two streams above mentioned, which flow into the river Wye in the County of Brecknock in Wales.

The geological formation of the drainage area consists of the lower silurian rocks, which, as in the case of the Liverpool and Manchester supplies, have been proved to be particularly well suited for furnishing a good supply of water. The drainage area is very sparsely populated, having not more than four or five persons to the square mile.

The average available rainfall calculated on in this scheme, after allowing for loss by evaporation, amounts to 36 inches, which will give about 99 million gallons per day, and after deducting the compensation fixed by Parliament of 27 millions, there will remain 72 millions for the supply of the district.

As in the case of Liverpool, the compensation awarded is very much above the dry-weather flow of the streams interfered with, and they will therefore profit very considerably. The only interests which will be affected, and that in a small degree, are the salmon fisheries, as there are no manufactories or mills of any consequence on the whole course of the

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Wye down to its junction with the Severn. The compensation works will cost £300,000, which the promoters considered altogether out of proportion to any damage which will be caused to the salmon fishing interests.

This scheme includes the construction of no fewer than six impounding reservoirs, three of which are situated upon the Elan and three on the Claerwen, having collectively a total capacity of 17,174 million gallons. It is intended to form all these reservoirs by the construction of masonry dams as in the case of Vrynwy and Thirlmere, the reason being, as in the case of the other ones mentioned, the absence of material from which to construct dams of earthwork in the usual way, and the existence of a rock foundation suitable for this purpose close to the surface all over the site of the dams right up to the top water level. It is unnecessary to say anything more on the subject of the nature of these works, which will probably be similar to those already alluded to.

The line of aqueduct between these reservoirs and the district to be supplied runs in very nearly a straight line from west to east, and consists of tunnels, built aqueducts, and cast-iron pipes. The tunnels and built culverts are to be constructed sufficiently large to carry the whole water available by this scheme, and it is intended to lay as a first instalment two 44-inch pipes capable together of carrying 27 million gallons, and these pipes are to be taken across all the rivers and important streams on bridges.

The length of the aqueduct is 73 miles, and it will deliver into a service reservoir at Frankley containing 200 million gallons, after which it will pass into filtering-beds designed to filter the first instalment of

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27 million gallons. The supply to that portion of the town above the gravitation level will be obtained by pumping.

The estimated cost of the whole works sanctioned by Parliament is about £6,000,000, of which sum it is intended to spend about 3½ millions for the first instalment of 27 million gallons per day. The area of supply included, besides Birmingham itself, the whole district lying within 15 miles of the line of the aqueduct.

Considerable opposition was raised to this proposed scheme first of all by the authorities in London, who indicated an inclination to appropriate the watershed for themselves, or, at all events, to prevent Birmingham securing it until sufficient time should be allowed them to make up their minds on the subject. It, however, was satisfactorily proved that the scheme, although suitable and indeed necessary for Birmingham, would not be so for London, seeing that the level of London is so much lower than that of Birmingham, and that there would remain for the use of the Metropolis, when actually required, a very much larger area of land, as yet unappropriated, which could be utilised for its supply, whereas a gathering ground of this kind, situated at a level sufficient to command a town like Birmingham with an elevation of 600 feet, is nowhere else to be found.

Some malcontents in the town itself advocated, on the plea of economy, the introduction of an inferior class of surface water, which was to be used for purposes for which absolute purity is not essential, but this suggestion fortunately met with little encouragement, involving as it would an actual duplication of all the pipes in the streets, and also inside the houses, which

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would lead to endless confusion, not to mention actual danger to life itself.

You will thus see that each of these water schemes has its own peculiarities, and that they are all what may be called progressive, both as to time and as to magnitude, and as to cost. The longer we live the more important the subject of water-supply is found to become. It is exercising the minds of all those who are now in authority under the recent legislation, and whose duty it is to see that pure water is, if possible, brought within reach of every inhabitant of our country, and in this connection it may be observed that there is generally more discontent and bad feeling induced by the proposed introduction of some comparatively trifling supply involving a small outlay, than has to be met with in cases where schemes are propounded involving such a large expenditure of money as has been cheerfully consented to by the more liberal-minded inhabitants of the large towns whose water-works we have been considering. Even in the case of our own city, the scheme which has recently been recommended as a suitable one for it, almost sinks into mere insignificance both as to extent and expense when compared with the gigantic schemes to which I have alluded.

I wish now to allude briefly to the condition of our Society, and I think it will be admitted that it is at present in a fairly prosperous state. At the beginning of the session there were 300 on the list of ordinary fellows. Since then I regret to say that eight have been removed by death, while two members have resigned, but the nett result is a membership of 320, being an increase of 20.

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The death of H.R.H. The Duke of Clarence and Avondale, who was elected an Honorary Fellow on the occasion of his visit to Edinburgh in connection with the opening of the Exhibition of 1886, has deprived us of an illustrious name in that class of fellows. The sad and sudden ending to his promising career, under such truly pathetic circumstances, is still fresh in the recollection of every one.

In the list of deceased ordinary fellows we find the names of the following:—

Mr J. Jobson Dickson, Chartered Accountant, and an Officer of the Queen's Royal Bodyguard of Archers. He joined the Society in 1844, and up to the time of his death he acted as auditor to this Society.

Mr Robert Craig, the well-known Papermaker, who joined the Society in 1865. After having for a long time conducted a most prosperous business as a paper manufacturer at Newbattle Mills, where his father preceded him, he died at the advanced age of 84.

Mr John F. Ker, who was a member of the Society since 1865.

Mr J. W. Johns, who joined the Society as recently as 1885.

Mr James T. Wilson of Restalrig House, who was a member of the Society since 1867.

Mr John Kippen Watson, for many years the respected Manager of the Edinburgh Gas Works, and a Fellow of the Royal Society, Edinburgh.

Mr James Crichton, Jeweller, a member of the Edinburgh Town Council, who died quite recently at the age of 60.

While all these gentlemen took a certain interest in the affairs of the Society, I must allude specially to the late Mr Imlach, who was more particularly

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identified with it, he having occupied the President's Chair only a few years ago. His death was all the more impressive on account of the painful suddenness with which it occurred, he having dropped down while walking on the South Bridge on the 24th December of last year. He was carried to the Royal Infirmary, but death had supervened before his arrival there. He was born in Edinburgh in 1829. He was a Surgeon Dentist by profession, and he attained considerable eminence in it. He was elected a Fellow of the Royal College of Surgeons in 1856, and about eleven years ago he was elected President, which position he held for three years. At the time of his death he was a Manager of the Royal Infirmary, and an active member of the Convalescent Home Committee, and many other charitable institutions. All throughout his professional and private career his natural kindness of disposition and geniality of manner endeared him to all with whom he came in contact.

In conclusion, I have to thank the office-bearers and members generally for their assistance and co-operation with me during the past session in carrying out the aims of the Society, and also to express the hope that while every member will do his best to promote its welfare by the introduction of new fellows, all those who have any subject of interest to communicate to the Society will not fail to do so, and that thus we may ensure that the Royal Scottish Society of Arts, which has hitherto held so important a position among the societies of this city and country, will continue to prosper in the future as it has in the past.

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Comparative Table showing the various Schemes alluded to.

	Drainage Area.	Yearly Rainfall.	Storage.	Daily Supply.	Daily Compensation.	Length of Aqueduct.	Population.	Cost of Scheme (Estimated).	Cost per Mill. Galls. Daily.
	acres.	inches.	mill. galls.	mill. galls.	mill. galls.	miles.		£	£
Glasgow, ...	48,000	36	8,986	40	13	40	850,000	1,500,000	37,500
,, (extension) . . .	3,100	60	–	35	–	–	–	1,000,000	30,000
Liverpool, ...	18,000	60	12,000	40	13½	77	800,000	2,100,000	50,000
Manchester, ...	11,000	88	8,000	50	5½	96	1,000,000	4,000,000	86,000
Birmingham, ...	45,562	36	17,000	72	27	73	600,000	6,000,000	83,000
Proposed Manor Scheme for Edinburgh . . .	9,310	27	2,703	10	5	25	370,000	602,364	60,236
,, (extension), . .	4,410	–	1,345	5	2½	–	–	204,076	56,162

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TRANSACTIONS

OF THE

ROYAL SCOTTISH SOCIETY OF ARTS.

On Flour and Malt Dust Fire-Explosions. By STEVENSON MACADAM, Ph.D., F.R.S.E., &c., Lecturer on Chemistry and Consulting Analytical Chemist, Edinburgh.*

TWENTY years ago, at the corresponding meeting of the year, being the second meeting held in November 1872, I read a paper before the Royal Scottish Society of Arts on flour-mill fire-explosions.

The subject was a novel one. Little or no information on the matter had been previously acquired or published, so that no assistance could be obtained from any prior investigations. The special occasion which had then directed my attention to the subject was stated to be a violent, disastrous, and lamentable fire-explosion which had occurred in a flour-mill in Glasgow. A large building of five floors, besides a sunk flat and attics, had its gable walls blown out, and was fired from top to bottom. The operations which were being carried on were of the most peaceful description, and were simply the cleansing and grinding of grain and the dressing of the flour. All the processes were proceeding in the most regular and harmonious manner, and yet in a space of time not greater than what was required to describe it—in a few seconds—two explosions took place; the mill was in ruins; the débris was simultaneously fired; the site of the mill was a roaring furnace; and, lamentable to relate, more than a dozen human beings were killed—in fact, out of twenty-seven workpeople engaged in or near the mill, fourteen were instantly killed, one was mortally wounded, eleven were more or less severely

* Read before the Society, 28th November 1892.

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burned, and only one, who was on an outer gangway, escaped unhurt.

The investigation proved the following general conclusions :—

(1) That fine flour-dust, when diffused through ordinary atmospheric air and lighted, formed a violently explosive mixture.

(2) That under certain conditions, such as the feed going off and the stones setting down on each other, or the accidental introduction with the feed of a foreign body, such as a piece of iron, a flinty piece of rock, or a common match, the millstones would strike fire, and lead to the explosion of the mixed flour-dust and air.

(3) That the explosive force of the most suitable mixture of flour-dust and air for forming this fire-explosion was capable of producing a pressure of 8 atmospheres, or 120 lbs. to the square inch ; and

(4) That the ordinary daily conditions under which many flour-mills were being worked in 1872 conduced to the recurrence of similar explosions of a more or less disastrous nature from time to time.

The novelty of the subject naturally and properly led to an animated discussion at the meeting of the Society, which was adjourned, and renewed at the succeeding meeting.

The War Office Authorities afterwards communicated with me on the subject, and I gave them the fullest information.

Suggestions were also given by me in the paper for obviating such explosions in flour-mills, or at least for reducing the results to a minimum; and the proposed precautionary measures were adopted by some mills in the country, and the subject thus passed from the theoretical stage in which it was assumed to be when I read my paper before the Society, and to a limited extent became a practical question.

Since 1872, explosions of a more or less disastrous nature have continued to occur in flour-mills, and, where investigated, such have been apparently due to the want of observance of the proper precautions.

Six years after my paper was read—in 1878—attention was

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specially directed to the matter by a series of explosions which occurred at Minneapolis in U.S., where the Washburn Corn-mills suffered from a fire-explosion due either to the millstones running empty, or to a foreign body getting between, and such inflaming of the flour-dust and air led to explosions in the dust-chambers and thereafter in the general body of the mill itself. This explosion was remarkable as being the primary cause of firing and exploding a second mill—the Diamond Mill—situated 25 feet distant, where apparently the disturbance of the air by the first explosion had raised the flour-dust, and mingled it with the air of the second mill, and then fired it. Still further a third mill—the Humboldt Mill—was almost immediately fired and exploded; and, finally, other three flour-mills, situated at a distance of about 50 feet, were fired, if not exploded. Altogether, property of the value of £200,000 was destroyed, and, lamentable to state, eighteen lives were lost.

Again, in 1881, nine years after my paper was read to the Society, a disastrous explosion occurred at a flour-mill in Macclesfield, in England, which laid a large part of the mill in ruins and one man was killed. The Coroner communicated with me on the subject, and I gave him all the information I possessed in regard to such explosions. Mr Thomas J. Richards, Government Inspector of the Board of Trade, also corresponded with me on the matter, and I gave him full reports on all questions relating to such explosions. He then acted as assessor to the Coroner during the inquiry, and subsequently issued a report to Sir William Harcourt, as Secretary of State, and which was presented to both Houses of Parliament.

In this report the Government Inspector states very clearly the different views still held then (1881) by millowners regarding these flour-mill explosions. He says:—"Since being directed to investigate the cause of this explosion (Macclesfield), I have made inquiries of a number of millers to ascertain the particulars of explosions which have occurred, and the causes of them. Some informed me that, in their opinion, the causes of explosions in flour-mills have not yet been satisfactorily ascertained. Whilst some millers doubt whether explosions can be produced in stive-rooms by millstones running empty, others disbelieve the possibility of

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explosions occurring there altogether; others again, whilst admitting this, are of opinion that the presence of some explosive gas, or extra pressure of air due to the action of the fan, is necessary to cause it, or that a certain electrical condition of the atmosphere must exist. One person of experience informed me that, in his opinion, a stive-room could at all times be safely entered with a light, except when there was observed in it the peculiar odour which is noticed there when one of the millstones has been previously running empty. The fact of such opinions being held is to be regretted, as explosions in corn-mills are liable to be regarded as mysterious, to which they have, in my opinion, no title. The precautions, also, which may obviate or lessen the effects of explosions are liable to be neglected." Then he says:—"Professor Macadam some years ago published in a valuable paper the results of some experiments he had made, proving the explosibility of flour-dust when diffused in air, and the views he enunciated are accepted by many millers. Finding, however, amongst some practical millers of long experience the existence of the opinions mentioned above, I considered it desirable to satisfy myself by actual experiment."

The Inspector then details various experiments he made, which were practically a repetition of those which were recorded in my paper, and the results of which entirely corroborated my own experiments and conclusions. He thereafter makes reference to the precautionary measures which were embodied in my paper, and commends their employment for averting and lessening such explosions.

The fire-explosions specially referred to occurred in flour-mills, and the explosive mixture was flour in a minute state of division; in fact, flour-dust and air which had been fired by millstones which had gone off the feed, or into which some metallic or flinty particles had passed.

I was quite aware at the time of reading my paper in 1872 that minor explosions had occurred from time to time in breweries and distilleries during the grinding of malt between millstones, and where malt-dust diffused through the air had been fired and exploded, leading to damage to roofs, &c., and occasionally to the scorching of attendants; but these were

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minor explosions, probably owing to the less fine state generally of the malt-dust as compared with the flour-dust, and also, no doubt, to the want of special dust in stive-boxes or chambers. Such minor explosions have been also repeatedly noticed since 1872. But it has remained till 1892 for a major or serious explosion to occur in a distillery where malt was being ground, and where a disintegrator, not millstones, was being used.

When the inquiry was placed in my hands, I was informed generally that an explosion had occurred in connection with the disintegrator, shortly after starting such, and before the feed was on, and that a blast of flame had travelled through various floors of the mill, doing much damage to the mill, and scorching more or less severely a number of the work-people.

The explosion was centred in the grinding-mill proper, the ground floor of which was mainly occupied by machinery, including a powerful disintegrator; the first floor contained five pair of stones, and malt and grain bins; the second floor, including grain and malt bins, with a passage in centre; the third floor also with grain and malt bins and a passage in centre; and the fourth floor, with a stive-box connected with the elevators, box coverings of various bins, and numerous shoots.

Communicating with the mill proper there were:—

On the Ground Floor.—Two doorway openings through the north wall leading to the kiln-furnace vault, neither of which had doors. The kiln-furnace vault immediately adjoining was provided with two iron doors to the outside, but opening in halves inwards, one on the north side and the other on the west side, and opposite the latter there was a doorway on the east side leading into the grain stores.

On the First Floor.—No door communication existed between this floor and any building north or south of the mill proper, but a spiral staircase passed through the floor at the north end.

On the Second Floor.—One iron door was constructed on the north wall leading to one of the kiln floors, and the iron door on the south wall leading to the second-floor store.

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On the Third Floor.—One iron door placed on the north wall and passing to the higher kiln floor, and one iron door on the south wall communicating with the third-floor store.

On the Fourth Floor.—One iron door built through the north wall above the roof of the kiln, and leading to an outside iron stair passing to an adjoining upper loft, and one iron door on the south wall communicating with the fourth-floor store, the roof of which has a large iron water-tank.

The whole of the floors running from the ground floor to the fourth floor communicated directly with each other at the north end by an iron spiral staircase; and the second, third, and fourth floor store-rooms communicated with each other at the south end by an iron staircase running up from the second to the fourth floors. The third-floor store-room was also furnished with a special iron door on its south wall leading to an iron gangway within the mash-tun house. Both the second and the third floor store-rooms were provided with doors at their east side for communicating with the lofts immediately adjoining.

The general circumstances under which this special fire-explosion occurred were stated by the officials to be that immediately after the disintegrator was set in motion, and before any feed was supplied thereto, an explosion took place within the disintegrator and its connecting hopper, which discharged a column of flame up the north spiral staircase to the upper floors with great force and power. This explanation of the cause of the damage done appeared to me most unsatisfactory, and incapable of accounting for the major part of the wreckage. For not only was much of the glass of many of the windows shattered, but other windows—frames and all—were blown entirely out; the kiln roof was severely damaged; the strongly built wall of masonry on the west front of the building was, on the upper floor, thrown about 4 inches off the plumb; heavy stones were thrust off the wall on the south side of the fourth-floor store-room down on to the mash-tun room roof; the mash-tun room roof was lifted some feet off its walls, and subsequently collapsed into the mash-tun room; an enormous iron tank forming the roof of the fourth-floor store, and capable of holding 40,000 gallons

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or about 180 tons of water, was moved at one part some 2 inches off its bearings and many of the lower plates were broken; and, finally, iron doors, with their wall bearings, were dislodged and hurled some distance, or were twisted and jambed so that they could scarcely be moved.

The inspections and examination of the buildings and machinery made by me disclosed many facts; which, when taken in conjunction with various analyses of the combustible malt-dusts and experiments, satisfied me that the damage was done by a series of explosions brought about by a number of objectionable conditions under which the mill was being worked at the time, and some of which at least are not uncommon at other mills.

First.—The hopper connected with the disintegrator and elevators on the ground floor was far from tight, so that the fine malt-dust could readily pass through and accumulate in the pit immediately below the disintegrator and surrounding the hopper. From 100 to 200 cubic feet of this fine dust could be there deposited—according to the height to which it was allowed to accumulate—and when such malt-dust is diffused through ordinary air, it forms a most powerful explosive mixture. The leakage of dust from the hopper into the pit was well known in the mill. For months it had been getting worse and worse. The leakages were attempted to be closed by a little packing from time to time, but the strong force of wind within the hopper when the disintegrator was in action, combined with the vibration of the rapidly revolving machinery, always dislodged the packing. Two small cleansing-doors at the sides of the hopper which had been originally secured with screw bolts and nuts, and ought to have continued to be so, were closed in the most temporary manner—one of them with a piece of stick stretching from the wall of the pit to the hopper. The results were that the dust passed readily into and accumulated in the pit, and was removed from time to time—occasionally in a couple of days—when the accumulation was found to interfere with the due working of the disintegrator and elevators. The pit, therefore, was a magazine of highly combustible powder, which required only mingling with air and a light

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to cause a more or less violent explosion, and the whole conditions in this pit on the morning of the explosion favoured such result.

Second.—The feed-shoot leading from the malt-bin to the spiral screw-feeder of the disintegrator was not capable of being closed properly by the "shut," and daily attempts had been made to stop the feed by stuffing the unclosed part of the shoot with bagging or waste, instead of arranging that the "shut" entirely passed and covered the whole mouth of the shoot, and that it was rounded off at the bottom so as to fit closely the shoot. The result of the faulty state of the "shut" was to render it highly probable that a limited feed from the malt-bin and shoot was kept on to the spiral screw-feeder, even when the feed was supposed to be off and the arrangement at a stand; and when the machinery was set in motion, this limited feed would pass on to the disintegrator, prior to any one opening the "shut" of the feed, and before it was intended that the machinery should be supplied with the malt.

Third.—The spiral screw-feeder leading from the malt shoot to the disintegrator was specially examined by me, and disclosed the fact that one of the iron collars connecting the spiral with the shaft was running loose from the spiral, and that two iron bolts, which had bound the collar and spiral together, were not to be found in the spiral-box, having apparently been carried onwards by the screw to the disintegrator. On direct questions being put to the officials regarding the occasional presence of foreign substances, such as pieces of iron or hard siliceous rock among the malt as it passed along the spiral screw-feeder to the disintegrator, it was admitted that there had been found in, and taken out of, the feeder, iron bolts and nuts and fragments of rock, and on one occasion an iron file. No screen whatever was used for keeping back such materials from passing into the disintegrator.

Fourth.—The elevators attached to the bottom of the hopper leading from the disintegrator by an upcast shaft and brackets to the fourth floor, and hence by a downcast shaft to the bottom of the hopper again, were connected at the upper

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part on the fourth floor with a stive-box, covered on the sides and top with flannel cloth, and in which it was intended that the fine malt-dust would be arrested. This stive-box was 13 feet long, 5 feet broad, and 2 feet deep, and when full would contain 130 cubic feet of fine malt stive-powder. No proper regulations existed for the periodic cleaning out of the stive-box and the connecting roan or conduit leading from the elevators, and the inspections made by me showed that these receptacles were practically full of stive-dust on the day of the explosion. Moreover, the flannel sides of the stive-box were faulty, there being large openings through which the stive-powder passed into the whole of the fourth floor, and this condition of matters had lasted for many months. The result was that the wooden covers of the grain-bins, and the flat surfaces of iron beams, &c., were heavily covered with the fine stive-powder, and practically the whole of the fourth floor of the mill had become an additional or supplemental stive-box, charged with combustible and explosive malt-dust. Connected with the elevators on the ground floor, there was a large pipe led through the north wall into an old stive-chamber constructed within the kiln-furnace vault, and this arrangement, though not in use for about three years, had the communicating pipe only stopped with a bag, and the interior of this stive-chamber contained much stive-dust.

It may also be stated, as incidental to the explosion, that the intermediate floors of the mill proper were the first floor, in which five pair of stives were placed, and the second and third floors, which were mainly occupied with the grain and malt bins. Connected, however, with the south end of the second, third, and fourth floors, and communicating with iron doors, there were store floors, in which, on the second floor, there were stored at the time of the explosion about 300 bags of bruised malt and about 220 bags of bruised oats; on the third floor, numerous bags filled with ground maize, besides a large quantity of malt dirt dust dropping from the travelling belt; and on the fourth floor, also bags filled with ground maize.

On the morning of the explosion, shortly after six o'clock, the machinery was set going for the running of the disin-

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tegrator with the connecting spiral screw for feeding, and the elevators, but the feed was not actually turned on. In four or five minutes after starting the machinery the explosion occurred. At that moment only seven men were in the mill —two were on the ground floor attending to machinery at some distance from the disintegrator; two were on the first floor preparing to set the stones in work; two were in the second-floor store proceeding with the filling and weighing of bags with bruised malt from a hopper led down to this store floor from the upper or fourth floor; and the remaining man was ascending the iron staircase leading from the south end of the second-floor store to the upper store floors. These men testify to the following facts regarding the explosion:—

(1) That explosions occurred in the disintegrator and connections which blew out an enormous blast of red and white flame from the pit underneath.

(2) That this flame rushed up the spiral staircase immediately alongside to the upper floors.

(3) That a similar flame rushed through the south iron door on the second floor, communicating with the second-floor store or malt store; and

(4) That a strong blast of flame from the upper floors came down the south iron stair into the second-floor store-room.

It was also reported that parties outside the distillery saw the roof of the mash-tun room lifted up, and flames escaping therefrom to a great height in the air, and thereafter the whole roof collapsed into the mash-tun room below.

On full consideration of the whole results of my inspections of the mill and machinery, and of all the circumstances of the explosion as related by the men at the time, I arrived at the following definite conclusions as to the origin and course of the explosion; or, rather, of the series of explosions:—

I. That the primary explosion occurred in the disintegrator and connecting hopper, and was due to partial feeding by the spiral screw, owing to the imperfect state of the "shut" from the malt-bin, and the carrying forward by the spiral screw-feeder of a piece of metal or fragment of siliceous rock; and such striking fire with the rapidly revolving arms of the disintegrator—six in number, and running 1400 revolutions

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every minute—instantly exploded the mixture of malt-dust and air within the hopper.

II. That this primary explosion was instantaneously followed by the diffusion of the bruised malt-dust accumulated in the pit underneath throughout the atmosphere of the pit, leading to a powerful explosion taking place in the pit, and probably, likewise, owing to its faulty state, in the hopper also.

III. That the explosions within the pit and hopper were immediately followed by the forcible discharge of malt-dust and flame in every direction and from every outlet by which such could find vent from the pit and hopper.

IV. That part of this explosive blast was propelled up the spiral staircase immediately alongside the disintegrator pit to the upper floors, slightly scorching the two men who were on the first floor—though out of the main line of fire—and who saw the lurid flame of burning malt-dust pass upwards.

V. That another part of the explosive blast was forced up the elevators to the fourth floor, and there clearing the pipe communicating with the stive-box would almost instantly diffuse volumes of this stive-powder, as well as that lying everywhere on this floor, throughout the atmosphere of the whole fourth floor, producing a magazine of explosive material equal to the cubic contents of the whole floor, and such would then be fired by the flame coming into the spiral staircase, and produce the most powerful and disastrous explosion of all the series, and capable of developing a pressure of eight atmospheres.

VI. That this explosion over the whole fourth floor of the mill proper was forcible enough on the north side to bend and twist outwards against its bearings a thick iron door, and to blow out a window, as well as damage the roof of the kiln; on the west side, to force outwards the strong masonry wall at one part as much as 4 inches; on the south side, to blow off a closed iron door with lintel and bearings to the other side of the store floor, and entering this floor to blow out windows, to dislodge large stones from the south wall and precipitate them into the mash-tun room; to displace a large iron water-tank forming the roof at one part about 2 inches, and to crack a large number of the bottom plates.

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VII. That the same explosive blast from the fourth floor also passed downwards by the spiral staircase to the third floor of the mill, blew the closed south iron door off its bearings, and hurled it into the third-floor store-room; and the flame, probably intensified by the explosively combustible nature of the malt dirt dust lying on this floor, the combined blasts entered the mash-tun room by the iron door (then open) leading to the gangway, and spent much of their remaining force in lifting the roof some distance, and causing its subsequent wreckage.

VIII. That the explosive blast from the fourth floor passing down the spiral staircase, probably preceded by the flame from the disintegrator pit explosion passing up the spiral staircase from the ground floor, rushed along the second floor, and passed through the south iron doorway, which was at least half open, into the second-floor store-room, where it burned two men severely, and met the explosive blast from the south end of the fourth and third floor store-rooms, which was being projected down the communicating south iron stairs, on the second lowest step of which the downward fire blast knocked over another man and burned him severely.

IX. That another part of the explosive blast from the disintegrator, hopper, and pit (par. III.) forced its way by the old pipe, leading from the bottom of the connecting elevators —and which was merely closed with a bag—into the old stive-chamber situated within the kiln-furnace vaults, diffusing much of the fine malt-dust throughout the atmosphere of the vault, which then became ignited and exploded with force sufficient to blow out windows and thrust outwards the large iron doors on the north side, which were constructed only to open inwards, and which were thus twisted and jambed, so that they were incapable of being properly opened or closed.

X. That as secondary results of the explosions, many of the bags containing the bruised malt and bruised oats and ground maize piled up on the various floor store-rooms were thrown down and some were fired, the flour-dust deposited on beams and other flat surfaces, and also that adhering to the walls, was charred, and wood-work was blistered. The windows of the mill and store-rooms were affected in a most unaccount-

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ably erratic manner; for, whilst those on the fourth floor and store-room which looked north and south were blown completely out, frames and all, those on the west wall (the masonry of which had yielded) had only panes of glass broken, and not a window frame was blown from its place. The same remark applies to the western windows on all the other floors.

The inquiries made by me also elicited the information that the explosion now specially described, though the most disastrous one which had occurred, was not the only one which had taken place in the mill of this distillery, and that four or five marked explosions had occurred at previous times. The one immediately preceding took place in 1891, when at least two explosions succeeded each other rapidly, and the flames rushed out of the pit underneath, rendering it necessary to turn on the water-hose to put out the fire in the pit. Besides these more marked explosions, there had been minor explosions, and characteristic crackling noises heard occasionally within the disintegrator, which were undoubtedly due to foreign substances, such as pieces of metal or fragments of stone passing in with the unscreened feed. Indeed, the whole arrangements and mode of working rendered it likely that such explosions might occur at any moment, and a continuance of the same or similar conditions in any flour or malt dust mill would necessarily be very unsatisfactory.

In order to avoid the recurrence of such explosions of a more or less disastrous character at flour-mills or distilleries, I am clearly of opinion that more careful attention requires to be directed to the observance of the following precautions and conditions:—

1. That in all cases the "shut" of the shoot leading from the grain or malt bins to the spiral screw-feeder shall always be capable of easily and certainly closing the shoot and cutting off the feed, and that the machinery shall be kept running thereafter until all the feed has been cleared out of the feeder, so that a daily examination of the spiral feed may be made to see that it is free from foreign substances, such as pieces of iron, fragments of stone, &c.

2. That the grain or malt shall be screened as it passes from the spiral screw-feeder to the disintegrator, so as to keep

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back any foreign substances which might strike fire, and that the screening be assisted by magnets placed in the course of the feed spouts which would arrest iron bolts, nails, &c.

3. That the hopper connected with the disintegrator and elevators shall always be kept tight, so as to prevent the fine dust from passing into the pit surrounding it, and thus leave the pit free from accumulations of combustible and explosive dust, and in a condition when the state of the hopper can be regularly seen to.

4. That any stive-box or dust-chamber situated within the mill proper shall be taken away, and a new stive-box or dust-chamber be constructed outside the building, on a blank wall away from doors and windows, and that the communication with the elevators be by a small passage in the wall protected by a light flap opening outwards.

5. That this outside stive-box or dust-chamber shall be covered and surrounded only by a light wooden casing sufficient to keep out the rain, and which will readily go to pieces should an explosion take place in the box or chamber, and thus admit of the explosion being spent outside the mill proper. The light flap in the connecting wall closing towards the mill when the explosion occurred.

6. That the stive-box or dust-chamber and the connecting roan or conduit shall be cleaned out once a week at least, and the dust-powder be duly used up or disposed of, and be not stored in the mill.

7. That all the floors of the mill, including all flat surfaces, should be cleaned up once a week, so as to avoid the lodgment of any quantity of the fine combustible dust, which, when disturbed and distributed through the atmosphere, may tend to develop an explosion.

In this paper it will be oberved that I have specially directed my observations to the causes of fire-explosions in flour and malt dust milling operations, and to the precautions which may be taken to prevent such, or, at least, to reduce their force to a minimum. It will be manifest, however, that my investigations both in 1872 and 1892 have an important bearing upon the questions of simple or ordinary fires occurring in flour and malt mills, and which are so common, even

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when no explosion has first taken place, or accompanies such. When the fine flour or malt dust is diffused in comparatively small proportion throughout the air and lighted, then flame and fire will be the result, and, indeed, in still less proportion flame may only ensue; but where the flour or malt dust is blown into the air in such large quantities as to form the proportions of dust and air capable of chemically saturating each other, then flame, fire, and explosion must result, owing to the enormously increased volume of gaseous matter produced by the chemical combination, and by the intense heat of the resultant products. I find that the proportion of about 25 lbs. of flour or malt dust distributed over and suspended in 1000 cubic feet of air forms the most explosive mixture of all, and consequently yields the maximum amount of force and damage. When the conditions under which any mill is running at the time admit of such proportions being produced in any hopper, pit, stive-box, dust-chamber, or mill floor, then a fire-explosion may result on the approach or presence of a naked light, or the millstones or the disintegrator striking fire, but where the proportions of dust in the air are less, then one of these so-called mysterious fires may alone take place.

Automatic Memorandum Clock. By JOHN DAVIDSON, Clockmaker, Wick.*

This clock delivers tablets with memoranda of appointments at any desired time. The means employed to carry out this invention are as follows:—

Connected to the movement of an ordinary clock is a horizontal disc with a number of slots cut radially, so that they are all in the same circle.

This drum or disc is fixed on a verticle shaft, which is made to revolve once in twelve hours by the works of the clock, to which it is connected by suitable wheels.

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* Read before the Society, 28th November 1892.

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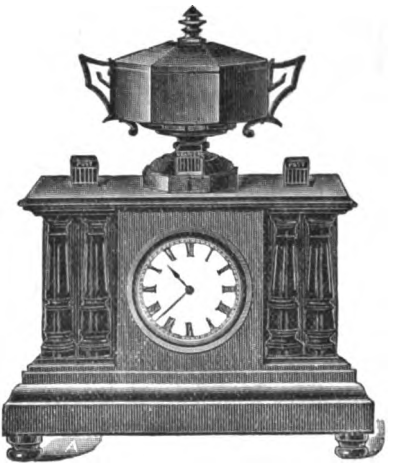
The drum is placed on the top of the clock, and enclosed in a suitable casing, preferably in the shape of a cup, with a hinged cover to open, as shown in illustration. The bottom of the cup is covered with sheet brass, with one slot or



opening (in the same circle as the slots in the revolving drum) directly above a small tray which is placed at the base of the cup for the reception of the tablets when they fall through.

The slots in the revolving drum are provided with a dial, indicating the time they will arrive at the opening in the fixed plate.

The memorandum of appointment is written on a bone tablet, then placed in the slot of the drum representing the hour at which one wishes to be reminded of an engagement or promise. As the clock goes, the tablet is carried round by the drum until it arrives at the opening in the fixed plate, when it drops through the opening into the small box or delivery tray at the base of the cup, the weight of the tablet causing the tray (which is balanced) to fall down until it meets a metal point, thus an electric circuit is completed, which causes the bell to ring, calling attention to the tablet with memorandum. The bell continues to ring until the tablet is removed. Supposing one wishes to be reminded of an engagement or promise at three o'clock, you write the

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nature of the engagement on a bone tablet (a number being supplied with each clock), then place it in the slot representing that hour; when three o'clock arrives the tablet falls into the tray already mentioned, and an electric bell rings until the tablet is removed.

As presently constructed, the drum or disc contains forty-eight slots, representing the hours, half-hours, and quarters of twelve hours, so that a man may have forty-eight engagements recorded per day.

The advantages of this clock will be readily seen and appreciated, as a man, instead of writing his engagements in a book (which he may forget to look at), writes them on tablets and places them in the clock, and can depend on being reminded exactly when an engagement is due, thus relieving him of the burden of recollection, and enabling him to give his undivided attention to the immediate work he may have on hand. This description applies more particularly to the office, but the clock may be equally useful for many other purposes, such as the sick-room or hospital, as a reminder when medicine, &c., should be taken.

It also performs the function of a perfect alarum clock, and has the advantage of ringing until the person using it gets up and removes the tablet from the delivery box. It may also be used as a call bell; by touching the tray by the hand any number of calls may be made.

It is therefore a timepiece, engagement reminder, alarum, and office call-bell all in one.

Note upon Mode of Calculating Spherical Refractors. By CHARLES A. STEVENSON, B.Sc., F.R.S.E., M. Inst. C.E.*

Alan Stevenson introduced into Scotland Fresnel's dioptric apparatus, the success of which resulted in his being employed by the English lighthouse authorities in designing their first

* Read before the Society, 12th December 1892.

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large installation. He made great improvements on the French system, both on the calculations of the lenses and on the general design; and he published, for the first time, formulæ for the construction of the refracting and totally reflecting prisms. He also designed the first holophotal apparatus which had been proposed by Mr Thomas Stevenson, and published the formulæ for calculating the prisms. The refractors of these apparatus which he designed were, on the inside face, cylindrical for fixed lights, and plane for revolving lights; but the introduction of the spherical refractor, and the fact that the largest refractors yet made are being constructed according to this design, has induced me to publish the investigation for calculating the profiles of such lenses when made spherical. If, however, the plane form of profile is retained for the lenses of the spherical refractor so as to be in echelon, no other formulæ than Alan Stevenson's are required. The spherical form of profile, although inferior, if of the same focal distance, to the plano-convex and the equiangular or biconvex lens as regards aberration and divergence of exfocal light, is nevertheless effective and useful if confined to an angle of 20° with a full lens. Beyond this angle, form of profile becomes all-important, and an equiangular prism of minimum deviation is best, as with this form there is minimum divergence with exfocal light.

M. Barbier's large 2000 mm. lenses referred to are badly designed, as the spherical portion subtends no less an angle than 32° 18′ above and below the focal plane, which, for a "full" or "uncut" refractor, is inadmissible at least with spherical profiles.

Fresnel selected prisms by testing their power of acting on focal light (absence of spherical aberration), and found that, although the biconvex form was best, it was not sufficiently better than the plano-convex to warrant his adopting it, owing to the difficulty of execution. Had he, however, subjected his prisms to the analysis of divergence, which, I pointed out in 1888, was a test of a suitable profile, he would have found that the advantage of the biconvex prism was very great, at least, for prisms remote from the focal plane where the two faces of the prisms are far from being parallel. Near the

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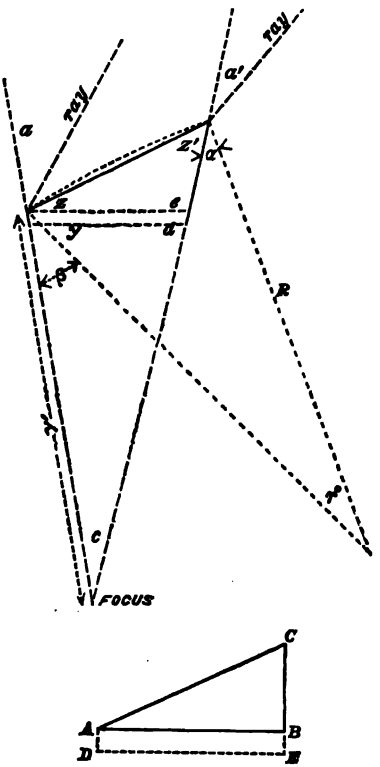
focal line, however, form of profile is of little consequence, and focal distance is of paramount importance. Thus, in comparing two lenses, one plano-convex and the other spherical, of the same extreme radius, say of 28° focal opening, the spherical is superior to the plano-convex for 20° from the focus, owing to it having greater focal distance and consequently less divergence; as although the form of profile is not so good it is there but little inferior to the plano-convex.

At 20°, however, the greater divergence caused by the profile of the spherical is just counterbalanced by the less



divergence caused by its greater focal distance, and here the two forms are equally efficient. At a greater angle than this the plano-convex prisms are superior, and are then, but only then, superior, and maintained so up to the 28°.

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It is essential, in making calculations of efficiency, to assume the flame to be approximately a hemisphere and not a sphere, and also to take into account the fact that a burner radiates light more strongly from the focal axis or bull's eye, so that a lens (such as a spherical lens is) of greater efficiency at the bull's eye than a lens (such as a plano-convex of equal extreme radius is) of less efficiency at the bull's eye will have an evident advantage as regards its efficiency to deal with the light from a paraffin burner.

Although the method of calculation can be curtailed, it would not be simplified thereby, and it is given therefore in a simple form.

Calculate angles of bend of rays, *i.e.*, angles a and a'. Then calculate angles α and β (see fig. 1) by the formulæ $\sin(\beta+a)=\mu \sin\beta$ where μ = index of refraction; $\sin(\alpha+a')=\mu \sin\alpha$.

$$\text{Then } d=\frac{180^\circ-c}{2}$$

$$y=d-\beta$$

$$z'=\frac{d+\gamma-a}{2}$$

$$z=d-z'$$

$$e=180^\circ-d$$

$$\text{and } r^\circ=180^\circ-2(z'+a).$$

$$\text{To get length} = AB = r' \sin\left(\tfrac{c}{2}\right)\times 2.$$

Note.—DE = radius to glass work $\times \sin\left(\frac{c}{2}\right)\times 2$.

$$\text{To get depth} = BC = \text{length (AB)} \times \frac{\sin z}{\sin z'}.$$

Note.—Total depth = CE = BC + BE.

$$\text{To get length} = AC = \text{length AB} \times \frac{\sin e}{\sin z'}.$$

$$= \text{length} \times \frac{\sin(180-e)}{\sin z'}.$$

$$= \text{length (AB)} \frac{\sin d}{\sin z'}.$$

$$R = \text{length (AC)} \times \frac{\sin(z'+a)}{\sin r^\circ}.$$

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Meteorology, Sea-Side, English Channel—Winter. By W. G. Black, F.R.C.S.E., F.R.M.S.* (With Four Plates.)

It occurred to me after investigating the climatal reasons why people go to the sea-side in summer, to ask myself why another set of people frequent the *coast resorts* in the *winter* in these days of changing of airs and scenes.

Now, the *former set* will consist chiefly of tourists and travellers, but the latter have a large mixture of *valetudinarians* and invalids, who, one would think, would be better advised to stay at home.

The same *portable instruments* were used as in the former inquiry, and the observations were taken morning and evening as before, both in the hotel as well as in the open air, and on the sea beaches or piers, and in all weathers, fine and stormy.

The *observations* were plotted out into *curves*, and this proceeding makes more visible and apparent the manifestation of *climatal* phenomena than any amount of reading figures from manuscript-tables.

The *curves* for all the instruments exhibit considerable oscillations, more than in summer; but those for the *sea data* continue steady all along notwithstanding the fluctuations of the air above it, and at once give the *clue* to the reason why certain people go to the sea-side in *winter* from their grimy cities.

The *winds* may blow warm or chilly, and the *sun* may shine or be obscured, and the weather may be wet or dry, yet the *temperature* and specific gravity *of the sea* continues steady all through, but only slightly on the decline in warmth, to the end of the year.

This *homogeneous* medium acts as a *governor* to the vagaries of the terrestrial climate, and soothes its asperities by the vapour and warmth given off by the sea during the process of evaporation by winds.

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* Read and illustrated with Diagrams and Instruments before the Society, 13th February 1893.

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In stormy weather, this *compensation* is specially increased by the *spray* from the surf and waves being carried inwards from the sea, which is then much warmer than the air inland, and continues so till the end of the year.

During the summer the *temperature* of the sea is *lower* than that of the air, but in the winter the *reverse* is found to be the case, and there is then a set period when these two phenomena *cross each* other.

In the eastern part of the Channel it would seem to come about the end of *October*, some weeks after the equinoctial period, and the *permanent crossing* seems to be maintained by the occurrence of northerly and easterly winds in the *anticyclonic weather* of the late autumn, after the equinoctial gales are over.

Further, the *warmth of the sea* is maintained on to the end of the year by the irruption of *SW. gales* into the Channel in winter bringing up warmer seas and warmer airs from the Atlantic Ocean.

The temperature of the *air on the beach* will be found to be a mean between that in the street in the town and the sea outside, and the fluctuations of the former seem much reduced the nearer the observation is made to the sea.

Hence, the climatal utility of *hotels and houses* being situated on *esplanades* and marine *parades* rather than inland, and at the back of the town, even though they may be not exposed at the other site to the storms and winds.

Waves and Surf.

At this time of the year all *sea-bathing* has ceased, since the beginning of October on the coast, owing to the increasing coldness and rawness of the air, and the increased action of the *surf* on the beaches.

But instead of this recreative and healthy exercise at the sea-side, it becomes appreciated now by visitors indulging in *promenading* the piers and esplanades and sea walls, in the enjoyment of brisk sea breezes and flashing sunlight, and the spectacle of lively waves and plunging surf.

In order to identify the waves for general recognition everywhere, the *waves* seen off a pier have been classified

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into four sets—viz., ripple, round waves, crested waves, and storm surge—and the *surf* has been called *light*, belonging to the two first sets, and *heavy*, to the two last sets.

Further, *special winds* have been associated with these sets of waves as light breeze, fresh breeze, and high winds and gales, so that on a person seeing the sea front agitated by "crested waves" he would say at once that there was a "high wind" blowing.

The appearance of the *colour of the sea* itself is also a point of interest to the marine climatologist, as it will be seen to get very muddy far out from the beach in weather producing heavy surf, especially in southerly gales, when the *storm surge* is driven straight on to the beach.

On the other hand, the sea will get *clarified* again when the wind blows offshore even strongly, and become *transparent*, this being due to the wave accumulation of the former condition being replaced by a wave depression—or, in fact, because the subaqueous currents are reversed—above and below.

There will, therefore, be no abrading of the beach by the backwash, and no silt stirred up by its descent, and instead there will be created a *reverse current* to the storm one, whereby the *bottom water* will seek to rise up the beach to the high-water mark, and then arrived, will be subject to the *offshore wind*, and be driven off on the surface of the sea to the offing.

So that then on seeing the *sea dirty*, we may conjecture that the winds are southerly (E. or W.) on the Channel coasts, and if it be clear, that they are northerly (E. or W.) on the same shores.

The spectacle of the *curling surf* on the beach in a gale is a very popular and entertaining one, and is due to be gazed at by hundreds of sightseers at the sea walls, who are also *mesmerised* by the thundering crash of the cataract and the rattle of the backwash in its descent.

The *height of the surf* or breaker in a heavy gale, it may be borne in mind, is deceptive to the stranger, as seen in full magnitude, as he imagines it corresponds to a wave at sea in the open.

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But really it would appear to be *twice the height* of the wave outside, as the whole *interior* of the revolving billow is then displayed, which on the open is submerged to its half diameter in the surface of the sea.

The crash of the *cataract* of water, however, at once displays the immense *potential power* there lies in the action of the revolving wave, slowly moving though it may in solemn grandeur; but the real *energy* is centred not in that motion, but in the revolution round its axis.

It may be likened to the *potential power* there lies in the spent *round shot* from a cannon rolling along the grass, which would break a man's leg if he attempted to stop it with his foot in front of its revolution on its axis, or to the momentum lodged in the periphery of the fly-wheel of a stationary steam-engine.

The observations of the phenomena of the sea were considered necessary to be carried out alongside of the observations of the air of marine health-resorts, in order to arrive at a proper estimate of the causation of the sea-side climate.

This marine influence does not appear to have entered into the programme of meteorological observations at all generally at these places, as I have only met about a couple of observers of the sea at the numerous sea-side resorts I have visited round the coasts of the United Kingdom.

Morning Observations at Hastings, from October 24 *to November* 21, 1888.

1. *Barometer* exhibited a mean of 29·92 in. for the morning and evening observations for four weeks in October and November 1888, and its oscillations consisted of two sets of elevation above 30·00 in. about Oct. 27 and Nov. 15, and two sets of depression below 30·00 in. about Nov. 1, and when SE. winds occurred, and Nov. 13, when SW. gale prevailed.

2. The *thermometer* in the air outside at this time, after the equinox, commonly fluctuates above and below 50°, and had a mean of 50·8° for the four weeks, and exhibited a deep depression on Nov. 7 during N.E. winds, when it had been cold weather for some days, with land fogs.

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3. The manifestation of *ozone* by Moffat's papers showed much variation, and a *diminished* intensity as the winter went on, and had an amount of 59, or a mean of 1·1 per diem, but was totally absent for eight days during *anticyclonic* winds from SE. and SW. and NW.

4. *Evaporation* of water in a cup showed much fluctuation from day to day, owing to the variation in the *winds*, from this side or that, as it was now less dependent on the heat of the sun to keep it at a steady rate.

The *amount* for four weeks was 1·15 in. or ·04 in. per diem, and it was absent altogether on nine days, owing to misty drizzle or wet weather.

5. The *temperature* of the *air* on the piers or beach followed closely that of the street, but with less curves, and had a mean of 51°; and the same extreme depression occurred on Nov. 7 owing to NE. winds blowing from the land.

6. The *spectroscope* could now only be used in the mornings, and showed much variation in the intensity of the dark vapour lines from 1, on Nov. 1 and 2, with dry easterly winds, to 4 on Oct. 26, during SW. winds with rain; and 3 on Nov. 13 and 14, during south-westerly gales and rain.

7. *Rain fell* on twelve mornings and twelve evenings in the twenty-eight total days, or about half; and, of course, was most prevalent during southerly and SW. and NW. gales about the end of October and middle of November.

8. The *temperature of the sea* in the mornings had a mean of 52·4° per diem, 1·4° higher than that of the air, and kept steady above 50° till Nov. 5, when it went below to 48° during easterly winds. It did not rise again above 50° till the 11th and 12th, when SW. winds returned to blow up the Channel, bringing in warmer seas from the Atlantic Ocean.

9. The *specific gravity* for the four weeks had a mean of 10·30, which was high, and especially during the end of October and beginning of November, when dry easterly winds prevailed and cold, dry weather.

10. Several *gales* occurred in the four weeks, one of anticyclonic type on Nov. 3 and 4, with SE. and NE. winds, and one continuous and strong *cyclonic period* beginning

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about Nov. 12, with deep depression of the barometer to 29·41 in., and lasting nearly a fortnight.

In other parts of the kingdom it culminated in a *critical* general *storm* about Nov. 15 and 16, when much damage was done and reported in the newspapers, but none occurred at this place.

11. The most prevalent *winds* were, as are usual in the autumn, from the SW. direction (12), the next in amount were from the SE. (9), and the third in rate were from the NW. (6).

Curiously enough, the *SE. winds* were connected with low barometer, and with the cyclonic disturbances from the westward, just as south-westerly winds sometimes are connected with anticyclonic systems, this being dependent on their position in the special quadrant of the circle of movement.

The *estimation of force* gave more in the evenings (89) than in the morning (84), and this seemed chiefly to be due to the occurrence of three calm mornings and only one calm evening. Otherwise, the *forces* of the SW. winds were about equal to those of the SE. winds, which may be due to their being part of cyclonic systems themselves, but in different quadrants.

12. *Cloud observation* was well displayed, and was more prevalent in the evenings than the mornings by 225 to 207, which was due to drizzle and mist winding up the day, during the prevalence of E., SE., and NE. winds down the Channel and off land.

It may also be conjectured that some part of it *was wafted from London* and the Thames basin as a fog by the northerly and north-westerly winds right across the Wealden Hills of Surrey, as could be seen any day on going to the rise and viewing the country inland covered by a black smoke bank.

This anomalous difference was known by the mornings being much clearer by eight bright ones to three bright evenings, and from there being a continuous series of *dark evenings* for sixteen days without a break in November.

13. The estimation of *wave-motion* amounted to 80 for the mornings and 93 for the evenings, which was coincident with the wind forces of 84 and 89 at the same time.

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The highest amounts occurred in the latter half of November during the prevalence of the *stormy weather* from the SW. on the 12th and afterwards, and the *lowest* degrees were observed in the beginning of November during the SE. breezes that came in, especially about the few days of Oct. 30 to Nov. 3, when calm occurred in the mornings.

Morning Observations at Eastbourne, from November 23 to December 21, 1888.

1. *Barometer* exhibited two main depressions during the four weeks, on Nov. 29–30 connected with *stormy weather* on the 27th, when a *cyclone* passed across Ireland, going eastward, and, again, on Dec. 21, when a *cyclone* passed through the Irish Channel; the mean was 30·056 in.

For the most of December the indicatiens were above 30·00 in. with cold, dry anticyclonic weather.

2. The *thermometer* outside in the air had now got below the 50°, but rose above it only during the gales of Nov. 27 and Dec. 3 from the SW., and went below 40° during the dry, cold weather of the middle of December, and it had a mean reading of 46·4° for the four weeks.

3. The manifestation of *ozone* was flickering and uncertain, but rose to 4 and upwards during the SW. gale of Nov. 27, 30, Dec. 3, 5, and 21, but was seen to be *absent* on eleven days out of the twenty-eight during NW. to NE. breezes and in calms, especially in the *anticyclonic* weather of the middle of December; the total amount registered came to 70, or 2·5 per diem.

4. *Evaporation* of water in the cup was likewise very flickering, from ·17 in. on Dec. 12 and 13 to ·15 in. on Dec. 4 and 8 during SE. dry winds and sunny weather to *zero*, on six occasions, when the weather was wet, misty, or calm.

5. *Temperature of the air* on the piers and beaches fluctuated similarly to that in the street, but with less ranges, and was noted at 50° and higher on sixteen days than in the latter for ten days, and had a mean of 48·1° for the four weeks, or 2° above the mean (46°) of the street.

6. *Spectroscopic* amounts fluctuated considerably, from

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being as high as 4 on five days during SW. and southerly weather, and as low as 1 on five days during misty, dark, damp days and calms.

This shows that the *maxima* are more likely to be seen in clear, transparent air, containing *invisible vapour*, than where it is floating in a visible atomic state, causing obscuration of light.

The total estimation amounted to 69, or 2·4 per diem.

7. *Rain* fell only on seven *days* during the four weeks, and was absent entirely in the middle of December, which made the piers and parades tolerable for visitors to promenade on, and confirmed the *raison d'etre* of going to the sea-side in the early winter.

8. The *temperature of the sea* continued to remain above the 50° till Dec. 10, though the temperature of the air had begun to go below it on Nov. 27, and the mean reading came to 49·6°, or 3° *warmer* than the air in the town.

9. The *specific gravity* of the sea, on the other hand, seemed to *rise* instead; due, probably, to absence of rain and increase of evaporation from the surface of the sea producing coldness and increased density, and the mean came to 1031.

10. The number of *gales* were fewer than in last month by two to five, and were only two, one on Nov. 27 from the SW. lasting one day, when the portable anemometer showed a pressure of $2\frac{1}{2}$–$3\frac{1}{2}$ lbs. per sq. foot, or 26–28 miles per hour, at the pier-head. The *other* happened at the close of the long anticyclone on Dec. 21 with S. and SW. gales and wet weather.

There were some days of *high winds* during this fine period from the S. and SE., especially on Dec. 12 and 13 which raised a *rough sea* and surf on the beaches.

11. The most *prevalent winds* were from the SW. direction (12), and the next from the NW. (6), and the third from S. and SE. (5); the former occurring during the first fortnight and the latter during December in the anticyclonic weather.

The force of wind estimated was, of course, more for the SW. winds, or above (2), till Dec. 5 when the figures went below, and so continued for the month at a low rate, except during the high SE. winds of Dec. 12–13.

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There were six *calm* days in December, and there was more wind in the afternoons than in the morning by 86 to 79, as is generally personally experienced.

12. The estimation of *cloud* was singularly varied, and showed more dark mornings than dark evenings, by 204° to 106°, which was due to the morning mist and drizzles, which cleared off as the sun rose.

There was the pleasant enumeration of thirteen absolutely brilliant *evenings*, or half of the time, without a cloud in the sky to obscure the *splendid sunsets*, which would justify anyone in going for change to the sea-side in the early winter from the foggy town.

13. The estimation of *wave-motion* amounts showed a total of 79, which belonged chiefly to the first half of the period, when south-westerly winds were prevalent up to Dec. 5, after which the wave agitation declined to 2 and below it, except on the SE. windy days of Dec. 12 and 13.

It may be added, finally, that the *hand anemometer* discovered that the winds were found to be of greater force in the streets and esplanades of the town than at the head of the piers; so that, what looked like a strong gale on land turned out to be only a *fresh breeze* on the sea.

This is seen to be due to the obstruction of the solid terraces and villas and crescents to the horizontal flux of the wind, which is forced to escape round the corners of streets, or over the roofs of the houses, at a much exaggerated and accelerated speed over the normal velocity on a flat.

Winter at Sea-Side Resorts—Hygienic Considerations.

In reviewing this sketch of the characters of a *winter climate* that are attractive to a certain class of visitors, it may be alleged that one reason may be stated that does not belong to the station at all itself, but to the one they *come from*.

This is the increasing intensity and extent of the *smoke fogs* of the cities, particularly of the manufacturing class, which now regularly take possession of them in October, November, and December, and drive all valetudinarians out of them to seek refuge in the *clearer air* of the coasts.

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After the *equinoctial gales* are exhausted by the middle of October, there sets in a calmer state of the winds, and some *anticyclonic weather*, which permits fogs to gradually accumulate in the valleys and basins of rivers and estuaries.

The *smoke* of the towns is not blown away horizontally, but is driven downwards again to the earth by the *cold air* descending from the upper atmosphere in the anticyclone. This also chills the *aqueous vapours* ascending from warmer rivers and lakes, and also from chimneys in towns, the result of combustion in furnaces and fires.

In November 1884 in London there were 21 foggy days, but none in December of much account; in October 1885 there were 5 foggy days out of 17, and in November 1885, 8 foggy days out of 14.

In 1886 there were 12 fogs in October for the month, and 11 in November entire, and 7 in December entire.

In 1887 there were 17 fogs for 25 days of November, and 14 fogs in 24 days of December.

In 1889 there were 23 foggy days out of 28 days of November and 16 in December out of 21 days.

About the end of December, or after the winter solstice of December 21, the *frosts and snows* commence, accompanied with some stormy weather; and these succeed in precipitating the fogs, or driving them away.

The *town* atmosphere thus becomes *purified* again from its autumnal miasmata and darkness, and more fit for the *residence* of the valetudinarians, and so they begin to *return* again to their homes about Christmas and the New Year from the coasts.

And now a different change in climatal conditions of the *sea-side resorts* commences in the sea *becoming chilled* down to the land degrees of coldness by the Arctic currents driven down from the N. by the NW. and NE. gales or blizzards into the Channel.

The *sea* therefore becomes no longer able to impart *warmth* to the coast climates, and the air has settled down to a raw and damp condition, which continues well on to the spring and summer months, and renders residence then at the sea side uncomfortable.

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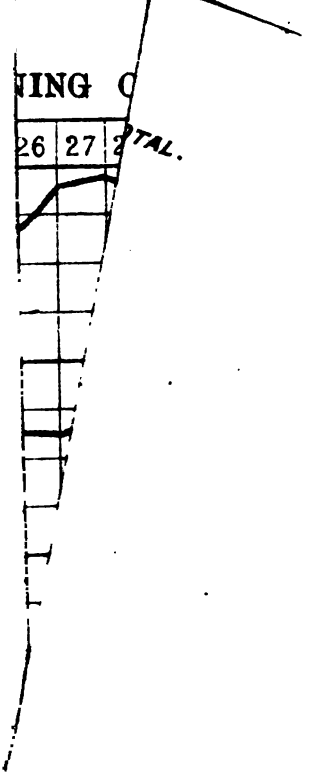

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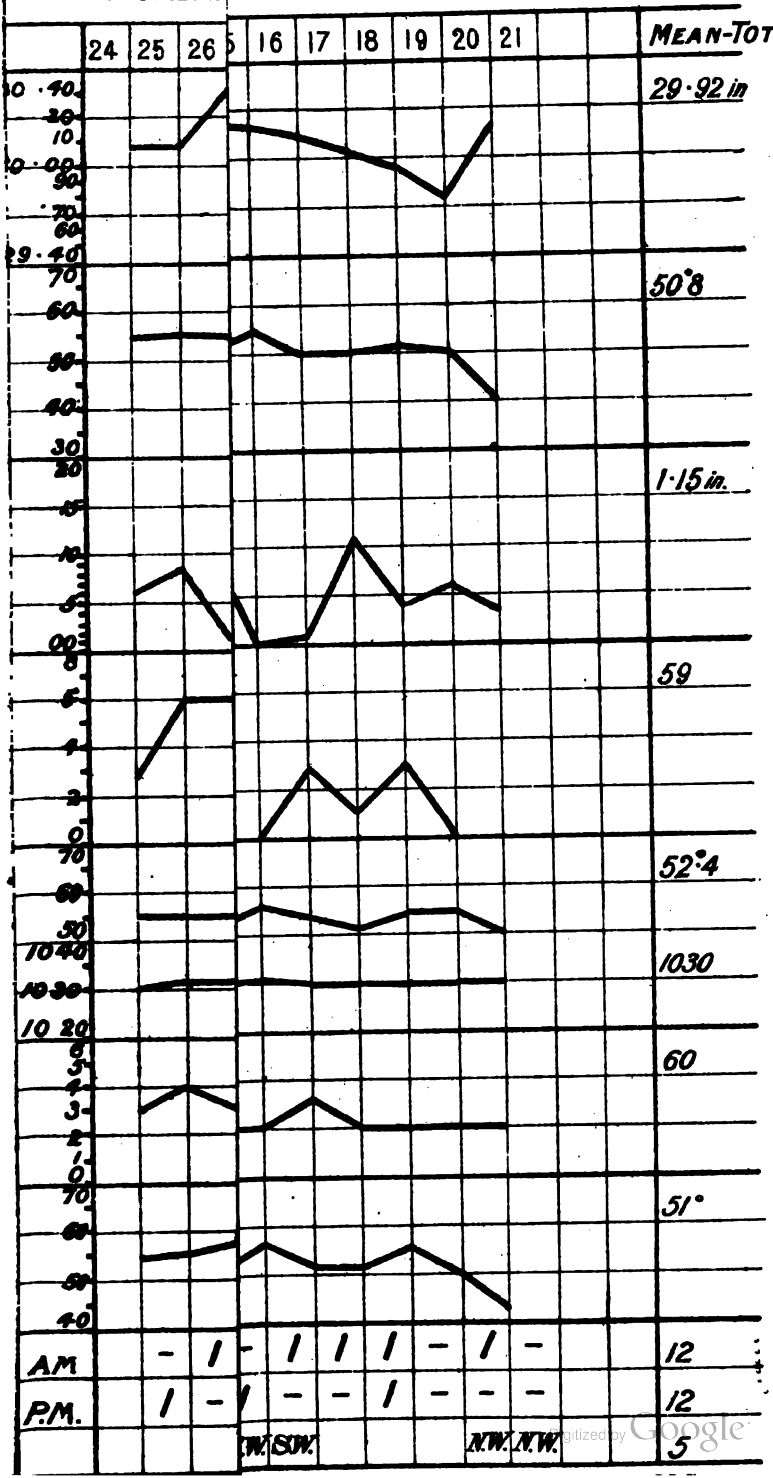
MORNIN 1888 — HASTINGS.



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ENING OBSASTINGS.

25	26	27	28	29	19	20	21			MEAN-TOTAL.
										29·94 in.
										52
										67
										84
										89
										207
										225
										80
										93
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/	/	/	/	/	/	/	/			6
/	/	/	/	/	–	–	–			12
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–	–	–	–	/	–	–	–			9
–	–	–	–	/	–	–	–			4
–	–	–	–	/	–	–	–			5
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W. C. BLACK, F.R.M.S.

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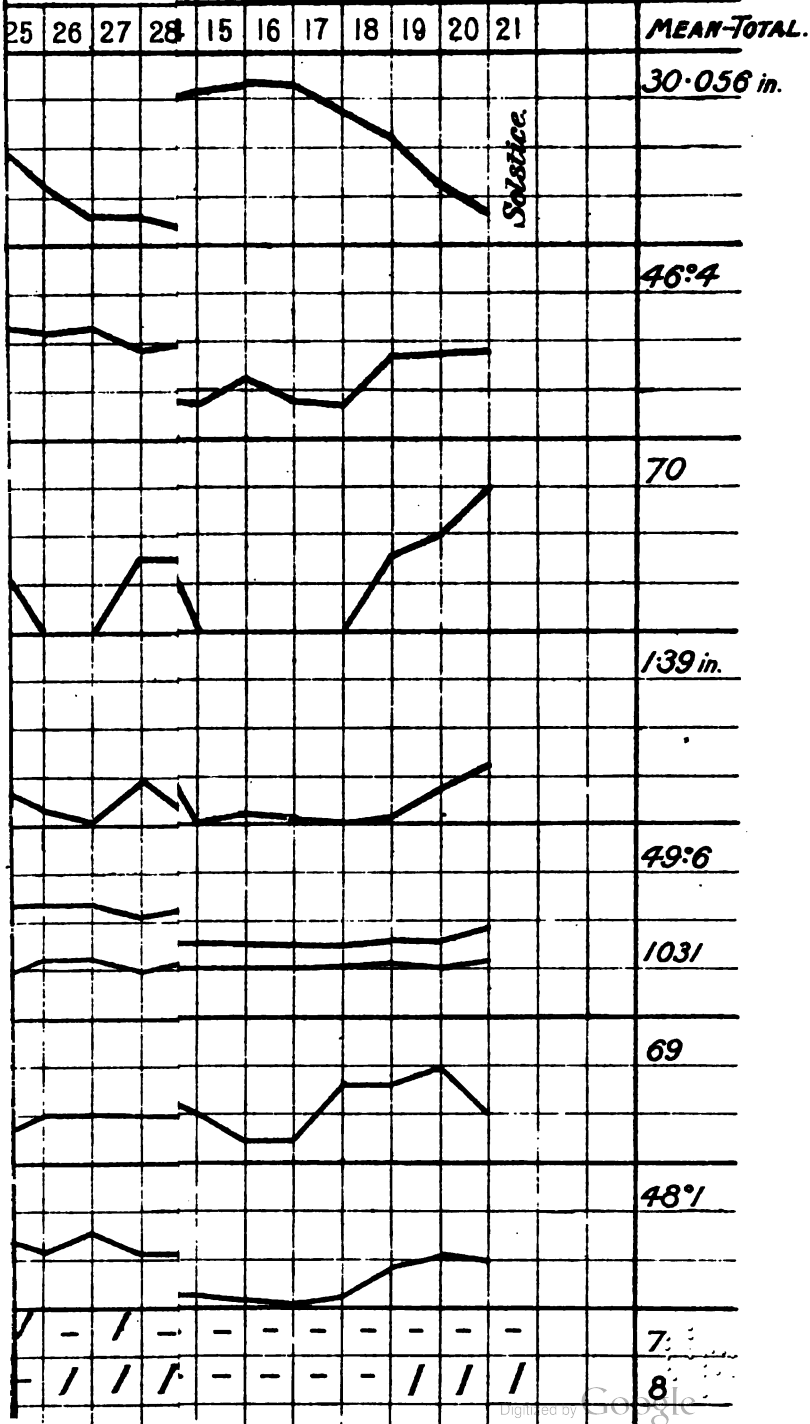
OBSERVATIONS — EASTBOURNE.



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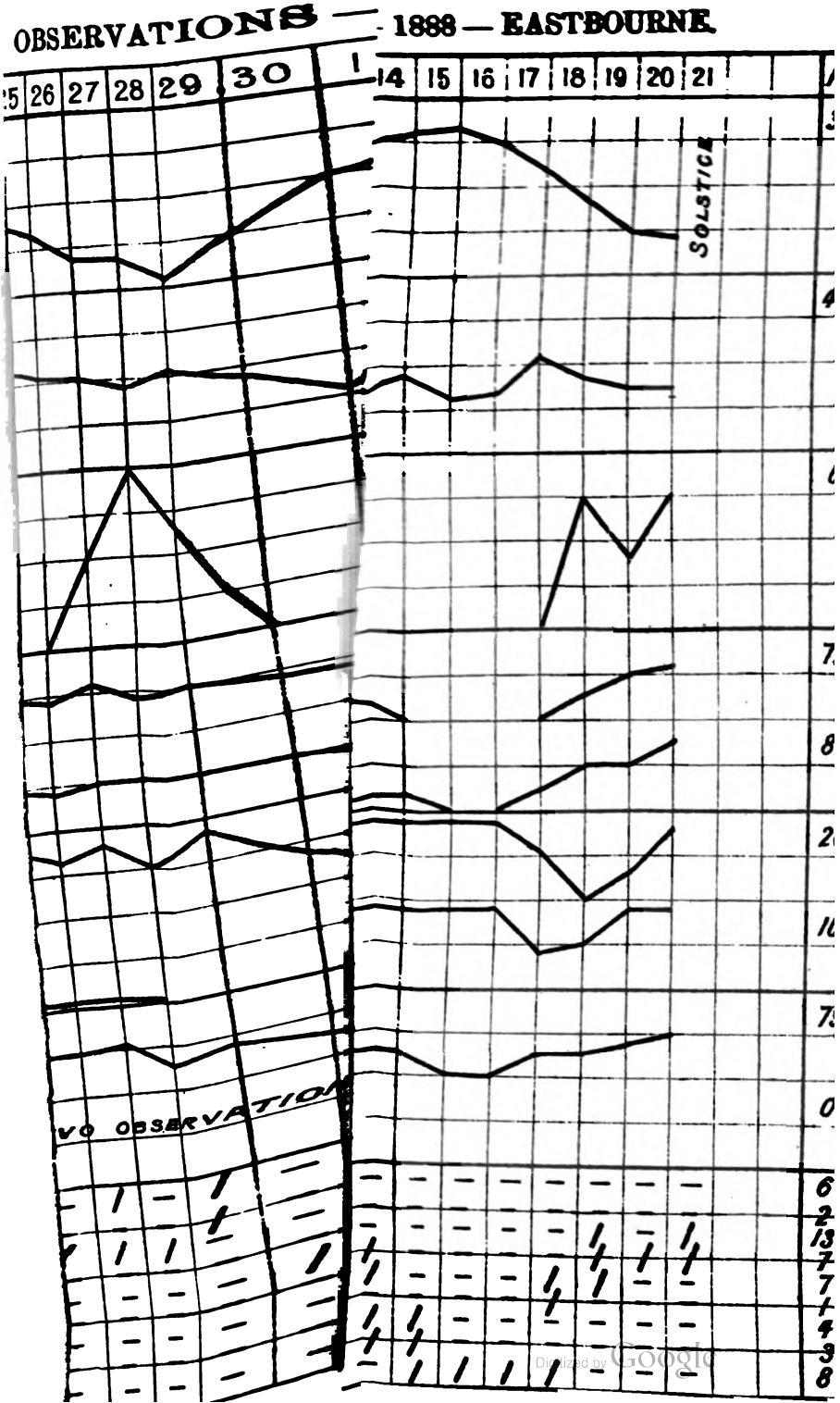
OBSERVATIONS — 1888 — EASTBOURNE.
25 26 27 28 29 30 1
14 15 16 17 18 19 20 21
SOLSTICE
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The *invalid* by coming to the coast during the months of October, November, and December from the cities and inland towns *escapes the fogs*, calms and mists, and malaria of the autumn; and experiences instead a fresher and warmer air—more breeze, more ozone, and more sunlight.

He also is aware that he may *promenade* the sea-walls and piers day after day, in fine weather or stormy weather, with invigorating effect on his constitution by the winds, and exhilaration to his mental system by the spectacle of various lively marine phenomena.

The freedom of the sailor from colds in all weathers at sea is reproduced in the *visitor* to the *sea-side* in autumn, who also knows that he could not expose himself so much to wet or windy weather in the streets of his inland town without peril to his health.

The greater amount of evaporation at the sea-side than there is in a town also promotes a useful hygienic result, by increasing at the same time the transpiration from the human frame, and thus promoting the clarifying of the *blood* of the noxious ingredients acquired in the polluted air of towns.

Electricity of High Potential and of Great Frequency of Alternation. By DAWSON TURNER, M.D., F.R.C.P. (Edin.), M.R.C.P. (Lond.), Lecturer on Medical Physics at the Surgeons' Hall, Edinburgh Medical School.*

The wonderful electrical phenomena lately exhibited by Mr Tesla and Mr Elihu Thomson are, from their physiological effects, not without medical interest. These will be referred to further on, but a few simple remarks to begin with about the physics of the phenomena may be of advantage.

The essential differences between the current that Mr

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*Read and illustrated by Diagrams and Experiments, 13th March 1893.

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Tesla uses, and that furnished by an ordinary dynamo, or induction coil, are that the alternations of his current are inconceivably rapid and the electromotive force exceedingly high; thus the alternations produced by a good induction coil may be about 100 per second, and the electromotive force from 500 to 10,000 volts; while the alternations of the current used by Mr Tesla vary from about half a million to ten or more millions per second, and the electromotive force from 100,000 to a million or more volts.

Similar effects in a humble way may be produced and studied by means of the following apparatus devised by Elihu Thomson.

To the secondary terminals of a large Ruhmkorff's coil (my own gives a six-inch spark) are attached thick, well-insulated wires, the one of which passes to the knob of a medium sized Leyden jar, and the other to its outer coating. The first wire is now carried on to terminate in the knob of a metal discharger, the second is coiled to form a spiral of about ten turns, which is placed inside a glass tube, such as a lamp chimney, around which a well-insulated fine wire is coiled. The thick wire after traversing the glass tube is attached to the other limb of the discharger.

The lamp chimney and enclosed wire spiral are now immersed in a glass vessel half filled with petroleum; the extremities of the fine wire coiled upon the chimney are brought up to a convenient height in glass tubes; the latter can be corked at the bottom and then filled with petroleum, so as to carry the insulation still further, for the glass by itself is of little use. The induction coil should be fed by six or more accumulators, or very large bichromate cells. The proper proportion to give the primary and secondary wires in the induction coil in the petroleum must be found by successive experiments. My primary wire is No. 16 B.W.G. and has ten turns; my secondary is of No. 30 silk covered wire and has about one hundred turns, and between each turn is a fibre of silk, but this can be omitted if the turns of the wire do not touch. On passing the current from the cells through the Ruhmkorff's coil, a continuous series of loud and bright sparks will pass between the knobs of the

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discharger—if they are at a proper distance apart (about $\frac{1}{8}$ to $\frac{1}{4}$ inch)—while the ends of the fine secondary wires will glow and yield bright crackling lightning-like sparks from one to several inches in length; vacuum tubes will glow if held merely in the neighbourhood of these wires; if one of the wires be attached to a metal plate, an extensive electromagnetic field will be created, in any part of which a vacuum tube may be lighted up. The current can be passed safely through the body, it scarcely excites the sensory nerves at all. Thus a vacuum tube held in one hand and at some distance from the apparatus will glow, if the other hand be holding one of the secondary wires; here the current is passing through the body to the vacuum tube, and returning by the legs and ground, and by the air from the point of the vacuum tube; if a readier return path be offered the current along the tube, either by presenting it to a gas-pipe, or by causing another person to grasp its other extremity, it will light up more brilliantly; the current can be passed through a chain of three or more persons connected by vacuum tubes, if the circuit be completed by the first and last persons holding the two terminals of the secondary wires.

The great frequency of the alternations of the current is due to the oscillating disruptive discharge of the Leyden jar; by no mechanical means could this frequency even be approached, a frequency which under favourable circumstances may reach many millions per second. The high potential obtained, 100,000 to one million or more volts, depending upon the ordinary laws governing induction coils, is raised principally by the extraordinary rapidity of the current changes.

If we turn to the physiological effects, so far as my own observations go, almost the only sensations the current appears to give rise to are due to the passage of accidental sparks.

If both the terminal wires or electrodes be firmly grasped before the current is turned on, no sensations whatever will be experienced, although the whole current is passing through the body

If one electrode be held, and the other hand be holding a vacuum tube lighted by the passage through the body of

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the current, no sensations will be experienced unless the tube be presented to the other electrode in such a way as to draw sparks from it, when a slight tingling may be felt.

If one electrode be grasped, and the bare hand be presented to the other one, a succession of vivid crackling sparks or a continuous glowing discharge, according to the proximity of the hand to the electrode, will pass between them; these cause slight burning and tingling sensations.

By placing the forearm between, but not touching, the two electrodes, vivid sparks will pass from each electrode to the arm; if these be kept up for a few minutes slight weals will be formed. If, however, the electrodes be pressed firmly against the opposite sides of the arm no sensations will be experienced.

No success followed an attempt to stimulate the ulnar nerve at the elbow, one electrode being applied to the external condyle and the other over the nerve.

The current may be passed safely through the cheeks, forehead, &c. Let two people grasp each one of the electrodes, and let the one present a vacuum tube to the cheek of the other, it will light up brightly without giving rise to more than a slight tingling. The experiment may also be performed directly. Grasp one electrode, and press the other one (holding it by an insulating handle) firmly against the cheek, side of the nose, forehead, over the closed eyelid, mastoid process, &c., no sensations will be experienced unless sparks be drawn, the optic nerve will not be stimulated (slight sparks will pass if hairy parts be traversed).

Seeing then that the passage of the current does not set up either sensory, special sense, or motor phenomena, has it, we may ask, any easily observable direct physiological effect? It appears to stimulate the vasomotor nerves, for slight local perspiration invariably accompanies an application, which is more marked if the part to which the electrode be applied be one that is naturally prone to perspire.

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A longer time will be required to study any more obscure effects (nutritive, &c.) which the current may have.

Various theories and hypotheses have been advanced to explain the immunity of the body to such currents. Thus it is suggested that just as static electricity resides on the surface, so these alternating currents of high potential (Sir W. Thomson) are carried along the surface, the phenomenon growing with the frequency of the alternations: we may suppose then, if these be sufficient, that the current will pass altogether by the skin surface, and not penetrate sufficiently to affect the muscles and nerves.

It is also suggested that the tissues cannot respond to such rapid alternations. The retina, for instance, only responds to vibrations of a certain rate, those that lie between 481 (red) and 764 (violet) billions per second; all others, the dark heat rays which stimulate the sensory nerves, and the ultra-violet actinic rays, are without effect upon it. In the same way the auditory nerve can be stimulated only by sound waves which vibrate from about twenty per second to seventy thousand per second. If either limit be transgressed the sound is inaudible. Is it not probable then that the motor and sensory nerves and muscles have also their proper limit of greatest rate of vibration, and that they are insensible to any stimulus that exceeds this? A degenerating muscle seems to afford us an illustration; a healthy muscle will respond to the ordinary rapidly interrupted current of a coil, but a muscle cut off from its nerve does not respond; a stimulus that lasts a longer time (a galvanic interruption) is required. But this has also been directly proved with regard to healthy muscle. Helmholtz and Koenig showed that a muscle does not respond to a stimulus that has a duration of less than 0·0015 of a second, and d'Arsonval, using alternating currents, found that if the alternations exceeded two hundred thousand a minute, not only do the muscles not contract, but the current itself is no longer perceived. Others suppose that it is quantity of electricity in ampères and not pressure in volts that affects the body; that though the voltage may be very great, the current strength is correspondingly small, and that this is still further reduced and negatived by the counter

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electromotive force of self-induction. Thus the two electrodes of a Voss or Wimshurst machine may be held, and the current passed through the body without its exciting sensation, so long as sparks are not drawn, and vacuum tubes may be lighted up by much the same methods as we have described; but in this case the current strength is really extremely small, probably not more than $\frac{1}{100}$ milliampère; while in Tesla's experiments it amounted to very much more.

Whatever be the true explanation, it is extremely interesting to have found, as Mr Tesla has, that it is possible to pass, as it were, the dangerous point in rapidly alternating currents of high potential, and to cause the human body to conduct a current, which would probably prove very serious, if not fatal, were it one hundred or one thousand times less frequently reversed per second.

A Hydraulic Valve for High Pressures. By Cossar Mackenzie, Edinburgh.*

Before explaining the construction of this valve, perhaps it would be well for me to explain that I mean by high pressures those which are generally maintained in hydraulic-power systems worked by pumps and accumulators, say from 500 lbs. per square inch upwards.

It has often been said, and I have no doubt that it will be readily admitted, that "the Forth Bridge would have been an impossibility without hydraulic power," and that "that monument of engineering skill is to a great extent due to the present advanced use and knowledge of water pressure." Every one knows the difficulty there is in keeping ordinary water fittings which are in constant use in a perfect state of repair. It will, therefore, be readily understood that with a

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* Read before the Society, 13th March 1893.

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pressure of, say, 1000 lbs. per square inch, the difficulty is immensely increased, and the result of leaky valves is not so much the loss of water as the loss of power, as with two or three leaky valves there is great difficulty in keeping up the required pressure. The efficiency, therefore, of each valve is of importance to the whole system.

Although our knowledge of the use of water under pressure is in a forward state, there are very few standard valves to be had for working cranes, hoists, and other hydraulic machines. Indeed, I think I am correct in stating that until a few years ago, valves for these purposes could not be purchased without being specially ordered and made, every engineer making his own valve in his own way as occasion required.

These valves are for the most part of three kinds :—

(1) There is the ordinary plug-cock, made specially of course for hydraulic work, with a long tapered plug and deep stuffing-box and gland. Nearly all the cranes and machines used at the erection of the Forth Bridge were fitted with these cocks.

The objection to the plug-cock is that when opened to admit water the pressure is at the same time exerted on the nose of the plug which presses back against the packing. On shutting the cock this pressure on the packing is relieved, and thus with constant opening and shutting the plug gets a little slack and the result is a leakage. The packing gland is then tightened down, and so on until the packing becomes perfectly hard and the cock gets too tight to work easily, then it has to be taken out, ground, and repacked.

(2) There is the slide-valve, made similar to the slide-valve of a steam-engine, and worked with a lever handle.

No doubt these are very good valves when well made, but in many circumstances they require very frequent re-facing and attention.

The motion of the valve being parallel to the seat, the face is partly uncovered at each stroke, and dirt particles in the water soon score the faces and cause leakage. Constant use, such as on a riveting machine, soon causes the valve to get stiff and unworkable; this is owing, in the first place, to the comparatively large area of the face or seat making the total

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amount of pressure on the valve something considerable. Further, the motion being parallel, the water under pressure in the valve chamber requires to be displaced at each stroke. Again, the fact that the piston necessarily requires to be packed at both ends also helps to make the handle difficult to work, and considerable lever power is always required.

(3) There is the piston-valve, of which there are various makes.

This is a long, narrow cylinder with the various ports or connections at different points in its length, and a piston or plunger which is worked up and down with a lever handle in the same manner as a slide-valve. The piston being hollow for a part of its length, the water is admitted to the different ports as the piston is worked out or in.

These are really first-class valves, and more easily worked than the slide-valve, but the cup leathers with which the pistons are fitted are always liable to be blown out, and at the best require frequent renewal.

The best valves now made for both water and steam are those which rotate more or less on their own seats, thus keeping themselves in order by a process of grinding or facing. This is the principle on which the valve which I have the honour to submit to you is constructed; in fact, I may almost term it a rotary slide-valve.

First we have a shallow cup or cylinder, the bottom of which forms the seat of the valve. In the seat there are in this case two ports (there may be more), one of these leading by a connection on the back to the operating cylinder. The other, which you will notice is in the centre, leads by another connection on the back to the exhaust or return pipe.

Then there is the valve or disc with spindle attached, the face of which disc is ground to fit the seat or bottom of this cup. On the face of this disc you will notice there are three ports, two on the same pitch circle as the one in the cup which leads to the machine. The other being in the centre will be constantly opposite the one which leads to the return or exhaust pipe. Of the two first mentioned, in the face of this disc, you will notice that only one of them is bored right

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through, and the other communicates through the thick part with the hole in the centre.

When the disc is placed on the seat, and the open end of this cup or cylinder is closed by a flange cover and packing gland, there will be a small annular space or chamber over the back of the valve. Into this space the pressure is led through the connection on the side. The pressure is thus constant on the back of the valve, assisting in keeping it tight.

Now, if the disc is revolved by means of a handle attached to the spindle until the port-hole, which is bored through, is opposite the port leading to the machine, the water under pressure will be admitted and act on the operating ram.

If now the disc is revolved until the other port on this pitch circle is opposite the port to the machine, the water will be exhausted back through the disc and through the centre into the exhaust or return pipe.

Should the valve be required to work a double-acting ram or two alternate cylinders, there can be two ports on opposite sides leading to these; then when the pressure port of the disc is opposite the one, the exhaust port will be opposite the other—the one ram will be pressing, and the other exhausting.

The advantage of the exhaust port being in the centre is that by no possibility can the pressure port come opposite the exhaust port. Another advantage is, that it prevents the *possibility* of the face becoming worn into a dish shape.

In order that there may be no chance of the water getting between the faces, there is a small check turned on the end of the spindle. A small screwed nut is screwed on to a piece cast on the top of the packing gland, and pressing against this check keeps the disc on its seat.

I do not claim that the idea of a disc-valve for hydraulic work is an entirely new one.

A Glasgow engineer patented a disc-valve for a certain purpose twenty years ago, and I have also lately learned that two Leith engineers patented one about two years ago; but both of these valves are only for the admission of the pressure, and do not exhaust the water, another valve being required

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for that purpose. In both of these valves the water may at times get between the faces, causing considerable trouble and leakage.

This valve will work well and keep tight with reasonable care under all circumstances, and it is quite evident that the rotary motion has everything in its favour and tends to the preservation of the valve. The power required to revolve the disc is very small, as the water does not require to be displaced to any extent.

Further, the spindle of the valve being merely required to revolve, the packing is hardly disturbed with the motion, and there is not a tithe of the wear and tear on the packing or leathers compared with the piston motion of a slide or plunger valve.

Valves of this kind have been at work on cranes for a considerable time, one of them replacing a slide-valve which required attention every three or four weeks; and not only are they absolutely tight, but they are as easily worked, and, if I may say so, the faces are in better condition than when the valves were first fixed.

On the Utilisation of Water for Power and Transmission of Same. By JOHN RITCHIE, C.E., Edinburgh.*

The subject of this paper is one which, in the present day, is exciting very general attention, and while I shall in the course of it require to touch upon what is being done in this connection in various parts of the world, it is more particularly with the possibilities of a much more extended use of water-power in our own country that I shall deal.

Water, next to air, is one of the most widely-distributed substances on the earth, and from the earliest periods of civilisation has been made use of by man for the production of mechanical energy. Only a mere fraction of available water-

* Read before the Society, 27th March 1893.

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power is, however, made any use of. In the words of Prof. Ayrton :—

"Countless wealth is being squandered in all the torrents and water-courses of the world."

It is difficult to arrive at correct conclusions as to the reasons which have retarded the development of water-power. The principal causes seem to be cheap coal, and the great improvements made in the steam-engine during the earlier years of the present century, and which improvements have been continued in an uninterrupted line to the present time.

Another cause, doubtless, is the great change wrought on the surface of this country during the past sixty years by an extensive and systematic course of drainage. At the beginning of this century land was not drained as it is now; and a great portion of it was not under cultivation, but existed as bog, marsh, or forest. The rainfall found a storage in the soil, which became a temporary natural reservoir, and by retarding the flow, regulated the feeders of our rivers better than at present. The introduction of drainage changed all this, and most rivers now come down in greater volume in a given time than they did before these improvements on the land were carried out. This, though an advantage to the land, is not so to the millowner who uses water-power. At least one-half of the whole rainfall is carried off in floods, which are not only of no use as a source of power, but a positive loss owing to the corresponding rise in the tail-races of the mills on the streams.

The choice of a situation and the necessity for expensive works in connection with water-power, where a large volume and a small fall had to be dealt with, have also had a restricting influence in extending its use. When coal rises in price, as it certainly shall, more attention will be paid to developing the natural resources of the country. Coal can only be made use of once for producing power, not so water; the cycle caused by the heat of the sun in the rainfall is continuous in its operation, and becomes a source of perpetual energy.

In connection with the duration of our coal, a word of warning was spoken in a recent lecture by Mr R. T. Moore, mining engineer, Glasgow, who stated that in 1845 the

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quantity of coal raised in Scotland was 4 million tons, in 1891 it was over 25 million tons. Speaking of the Lanarkshire Coalfield, from which more than one-half of all the coal raised in Scotland was produced, his opinion was that the coal in the whole of the upper seams would be exhausted in twenty years, and that in the lower seams in sixty years, allowing for an increase of 2 per cent. per annum; and as this state of things must apply to a greater or less degree to the other coalfields, the subject is fast becoming one of national importance.

As a nation, we are much behind those on the Continent of Europe in making use of water as a source of power. In Switzerland, the South of France, and the more mountainous parts of South Germany, most of the streams are used for industrial purposes. The United States and Canada have led the way in the New World. The success which has there attended concerted action on the part of landowners through whose territory rivers flow, and the large revenues which are derived from water rights, ought to be an incentive to the landowners in our own country, especially at a time when land is little better than a drug in the market, to follow a like course.

The invention of electrical transmission of power has opened up an entirely new field for, and given the use of water-power an enormous stimulus.

Factories, mills, and other works have generally been erected near rivers having natural waterfalls, which are often in places comparatively inaccessible, and where a large sum has to be expended in making roads or railways to bring the raw material to, and take away the finished product from, the factories. By placing turbines at the source of power, and generating electricity, the power so produced may be transmitted electrically many miles with a very small percentage of loss, and by means of electro-motors be applied to drive any kind of machinery.

It is impossible in the course of this paper to do more than simply enumerate some of the vast hydraulic works that have been carried out in recent years, or that are in progress.

Switzerland uses 80,000 horse-power out of a possible

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600,000, and is rapidly adding to it; and this has already had a sensible effect on the quantity of coal imported. Most of the large towns in Switzerland, and even quite small villages, enjoy the advantages of the electric light, and the use of electrically distributed motive power, for industrial purposes. Switzerland is thus in a position to compete as a manufacturing nation in the markets of the world, although her position geographically is against her as far as export is concerned.

In no other country has so much attention been paid to hydraulic machinery, and it is noteworthy that in connection with the utilisation of Niagara the turbines to be used on the American side have been designed by Swiss engineers.

The water-power of Sweden is beginning to be utilized to a large extent, and will ultimately be a source of immense wealth to that country. The largest transmission installation in Northern Europe is now being proceeded with. The power station will be at Hüll Lake, where four turbines of 100 horse-power each will be placed.

Five steam-engines at present used for pumping and winding at some extensive mines will be replaced by a corresponding number of electro-motors; great economy in working is anticipated from this scheme.

In certain districts of Spain, both in connection with mining and manufacturing, a great extension is taking place in the use of water-power.

In a journey through the North of France in connection with some hydraulic works a few years ago, the author was much struck with the careful way the water was husbanded for the production of power in those districts remote from a coal supply; and small but prosperous communities were to be found whose whole existence depended on the constant supply of water to the mills and factories.

Rome has had the benefit of the electric light for the past six years. Originally started as a steam-driven generating plant of 2700 horse-power, the cost of coal told heavily against its commercial success, and the Gas Company united with a company which was formed to utilise the Falls of Tivoli, 16 miles from Rome. The principal waterfall is 110 metres (360

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feet), and flows at the rate of 3¾ cubic metres per sec. (7920 cubic feet per minute).

This plant has been successfully at work for nearly two years, and the saving effected is most marked.

This is the most important instance of long-distance generation and distribution by alternating current dynamos and transformers in Europe, and as such possesses a peculiar interest.

There are many other hydraulic works being carried out on the Continent at the present time, but we have not space to describe them.

There is one, however, which is somewhat unique. This is in connection with the lighting of the little town of Market Weiz in Austria, a most interesting description of which appeared in a recent number of the *Electrical Review*.

The power is derived from a small stream which flows near the town, and is sufficient to provide for the public lighting of the streets, and also for a great many private residences, as well as provide power during the day to several manufacturing establishments. The whole of the installation has been carried out by an engineer, a native of the town, assisted by local tradesmen; all the machines, transformers, and other plant having been made on the spot.

There are many small towns in Scotland quite as favourably situated, where, if more enterprise were shown, similar results might be obtained. The interesting experiments carried on during the recent Frankfort Electrical Exhibition have proved conclusively that electricity for light and power can be conveyed over long distances with a comparatively small percentage of loss.

Water-power is more largely used in the United States than any other country in the world. From a paper read before the American Statistical Association, it is stated that in 1880, 1½ millions of horse-power was utilised. About 36 per cent. of the whole power in the States is water-power.

Much of the success attending the efforts of American engineers and manufacturers in connection with the use of water-power has been due to the united action on the part of the riparian proprietors, and the laws which regulate water rights,

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so that it has been possible to carry out systematically great hydraulic works, which have even, one might say, a national character, so much does the very existence of some of the largest manufacturing towns in the States depend on the continuous and successful working of these.

The town of Holyoke possesses the most important water-power in the States: here a fall of 60 feet occurs on the Connecticut River. The volume of water averages 360,000 cubic feet per minute, and is capable of producing nearly 30,000 horse-power. These vast works are the property of the Holyoke Water-Power Company. The annual charge to the millowners only amounts to $4·35 per horse-power, which is without doubt the cheapest power for manufacturing purposes in the world.

The average cost of water-power in the United States is, however, much higher than at Holyoke, and including cost of water and interest on works and for repairs, it amounts to £4, 15s. per annum. The average cost of fitting up a water-power is £14 per horse-power. No steam-engine can compete with this, which is partly an explanation of the present depressed condition of the milling industries at home, and the low price of flour imported from the States.

Pelton Wheels.—On the western slope of the Rocky Mountains much has been done to utilise the water provided for the various processes of gold-mining, to drive stamps and other machinery, which formerly were driven by steam-power. The falls are so high that no ordinary water-wheels, or even turbines, could be adapted. The power is, therefore, developed by Pelton wheels or large jet motors. These have been particularly successful, and are used on falls of 1800 feet to 2000 feet. They have entirely revolutionised the mining industries in the Western States.

Niagara.—We cannot leave the subject of water-power in America without stating a few particulars of the great work now in progress at Niagara. Few readers but are more or less familiar with this project; but so many unconnected statements have been made from time to time, that they are apt to prove a little confusing.

A comparatively small portion of water from above the falls

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has been used for a number of years to drive mills placed along the banks, the water being conveyed in an open cutting and discharged into the stream below the falls after passing the mills.

The main features of the present gigantic scheme are as follows:—

A canal 500 feet wide and 12 feet deep opens into the river about a mile and a half above the falls, the opening to the canal points slightly down the stream, so that ice or other floating débris may flow past the mouth. The width of opening is such that the speed of flow is only 100 feet per minute when conveying 600,000 cubic feet of water per minute. In addition to the main electrical generating station, arrangements have been made to draw off water at various points to suit works which may be established on its banks.

The turbines are to be placed in wheel-pits 175 feet deep; the lower part of the wheel-pit communicates directly with an underground tunnel, 6770 feet long, 21 feet by 19 feet, constructed with a fall of 7 per 1000. This tunnel discharges into the river below the falls, and is capable of carrying the water, which will produce 100,000 horse-power, under a working head of 140 feet.

The turbines are to be of 5000 horse-power each, and certain novel and very special features have been evolved during their design.

The details of the means of transmission from the Falls to Buffalo do not seem to be finally determined, but the company have satisfied themselves that power can be supplied in that city at from £3 to £5 per annum.

On the Canadian side of the river it is proposed to obtain 250,000 horse-power. It is here intended to use Pelton wheels or large jet motors coupled direct to Ferranti dynamos.

The special advantage which Niagara possesses as a source of power lies in the great regularity of the flow, the lakes forming immense natural reservoirs, so that the quantity of water is nearly the same all the year round.

India.—The Indian Government has for many years been developing a system of water storage for irrigation purposes,

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the greatest the world has ever seen. Notwithstanding the enormous cost of some of these projects, they have not only fulfilled their primary object, that of preventing famine in the districts they were intended to benefit, but in many cases have returned a handsome profit on the outlay. The largest works at present being carried on in India are in connection with the construction of an immense dam across the Periyar River in the Presidency of Madras.

This dam will impound 13,000 millions of cubic feet, and is 178 feet in height above the bed of the stream. The outlet sluice is at such a level that water is taken from a valley which has a very heavy rainfall, and conveyed to another where comparatively little rain falls, by means of a tunnel through the hills. In the first mile after passing through the tunnel there is a fall of 1200 feet. The water-supply is capable of producing 50,000 horse-power day and night throughout the year, without interfering in any way with its use for irrigation purposes. It is expected that power can be supplied at the rate of £1, 10s. per horse-power per annum, and this will enable it to be electrically transmitted to several large towns in the Presidency. Steam-power in India costs, as a rule, 10 to 20 times this amount.

The water in the river is at present used to drive turbines which give motion to the stone-breakers, mortar-mills, hoists, and other numerous machines used in the construction of this important engineering work. These turbines were designed and constructed by the author, and have now been at work for over three years.

There are many other parts of India where the water stored in irrigation tanks, or reservoirs, is being made use of for power purposes; the water level of these tanks is from 20 to 60 feet above the outlet sluices at the end of the rainy season, and gradually falls to 4 or 5 feet.

We have thus briefly enumerated a few of the leading centres of water-power abroad.

In Scotland, from the years 1825 to 1840, a very considerable increase in the use of water-power on a large scale took place, and some very extensive works were erected, principally in connection with the introduction of cotton manufactures.

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The principal of these are Deanston, on the Teith; Stanley, on the Tay; Catrine, on the Ayr; and the Shaws Water-works, Greenock. We have recently had an opportunity of examining these works, and found most of them working up to their full capacity, although cotton is not now the staple industry.

Deanston.—These works are situated on the river Teith, near Doune, about 9 miles from Stirling, a fall of 33 feet is obtained by a weir about a mile above the works; four water-wheels by Fairbairn produce nearly 400 horse-power. The wheels are 36 feet in diameter; several turbines have been added in recent years.

Catrine, in Ayrshire.—Two wheels, 50 feet in diameter, give out 240 horse-power with a fall of 48 feet. The storage here is by large reservoirs. These wheels have been continuously at work for sixty years, and have required few repairs.

Stanley, on the Tay, near Perth.—Here 200 horse-power is obtained by a combination of water-wheels and turbines.

Greenock.—This is one of the most interesting examples of the successful storage of water for power on record. The natural features of the ground lend themselves most favourably for the adoption of the system of storage carried out here, and which has been in constant use for sixty-six years.

The rainfall in this part of the country is about 60 inches per annum, and in order to make use of the rainfall on an area of about 60 square miles, a reservoir of 295 acres was constructed, a second of 40 acres, besides several smaller ones, the aggregate capacity being 310,000 million cubic feet of water. The main water-courses are 6 miles in length in two lines, each conveying 1200 cubic feet per minute. The total fall is 512 feet.

The supply is perfectly regular, the reservoirs being large enough to contain the full demand for six months, so that in a wet year none is wasted, and in a dry year there is no scarcity.

The result of this scheme has been to place in the suburbs of Greenock a series of mills and factories, the machinery of which is driven by water to the extent of 2000 horse-power.

A portion of the town is lighted electrically, the power to

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drive the turbines and dynamos being derived from the water entering the service reservoir in the town, which it formerly did without doing any work. There are, doubtless, many towns where a similar arrangement might be carried out with advantage to the ratepayer.

The Shaws Water-works cost £85,000, and after being profitably carried on for many years by the original company, were sold to the Corporation of Greenock for £158,000.

Rainfall.—As the rainfall is the natural origin of all running streams, it will be useful to examine it in a general way, and then more particularly with reference to our own country.

In England the average rainfall may be set down at 32 inches.

It is least in the south-east, 20 in Essex, greatest in the north-west, at Keswick it is 67 inches, and at Seathewaite it has risen to 141 inches.

At Greenock it is 60 inches.

Some parts of Argyleshire, Wester Ross-shire and Inverness-shire, with the whole of Skye, have more than 80 inches of rain in an ordinary year.

The average for Scotland is 36 inches.

In Ireland, although the air is more moist and the effect of rain is more apparent on the land than in either England or Scotland, the rainfall is set down as 36 inches.

A very slight investigation into the latent dynamic force stored up in this water will impress us with the enormous waste that is going on.

Take England and Wales, the average height of the land above the sea is estimated at 250 feet, and the water which flows in the rivers has an equivalent fall. The area of the country is 58,300 square miles. Taking the rainfall at 32 inches, we have a total rainfall for the year of 160,524,515,500 cubic yards; allowing two-thirds of this to be lost from evaporation and absorption and one-third to reach the sea, we have 53,508,171,852 cubic yards, weighing 40,310,285,713 tons, and capable of producing 1,158,700 horse-power, acting day and night throughout the year.

Applying the same rule to Scotland, the area of the country

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is 31,324 square miles, average rainfall 36 inches, total rainfall for the year 97,029,222,400 cubic yards; allow one-third only of this to reach the sea and we have 32,343,074,100 cubic yards, weighing 24,160,276,360 tons, average elevation above sea-level estimated at 450 feet, this is equal to 1,120,600 horse-power acting day and night throughout the year.

Worked out in the same way, Ireland has a water-power of over 1,000,000 horse-power. It is not practical to use the whole of this power. In the navigable parts of rivers, weirs could not be constructed, and in many places the application would be too expensive to produce an adequate return on the first cost, but there still remains an immense power available for industrial purposes at present unemployed.

The great drawback to the extension of water-power is the difference between the summer and winter supply, involving the use of a steam-engine to supplement the power in dry weather, with a corresponding expenditure of capital on plant which is unproductive during a great portion of the year, and it is in this connection we have to deal with the important question of storage.

We have already considered the total quantity of water available in England for all purposes. For domestic and sanitary purposes, the consumption is not more than 25 gallons per head of the population per day. This gives 725 million gallons per day, or 264,625 million gallons per annum. Add to this the water for farm and manufacturing purposes, say 2000 million gallons per day, this gives us an approximate yearly consumption for all purposes of 994,625 million gallons; but as the annual rainfall amounts to the enormous total of 27,008,511,999,906 gallons, the annual consumption for every purpose is only $\frac{1}{27}$ of the whole, or 1·17 inch of rainfall for the year over the whole country.

Comparing Scotland in the same manner, the contrast is still more striking: allowing the same quantity per head of the population of 4 millions, we obtain 100,641,175 gallons per day, 36,734,028,800 gallons per year, allow 300 million gallons per day for other purposes, we have a total consumption of 146,234,028,887 gallons per year, or only $\frac{1}{184}$ of the whole rainfall, or equal to ·32 of an inch.

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The figures given clearly show that in the driest possible season there is abundance of water for every purpose, and that it is only a question of storage.

The results of the investigations of Denton and others go to prove that half of the rainfall passes off in floods, that it has merely the effect of temporarily raising the stream, and in the existing state of matters, except in a few rivers where compensation reservoirs have been constructed, no advantage whatever can be taken of this large quantity of water. amounting to the whole of the average flow in our streams.

The question is,—Can it be made to pay; would the construction of reservoirs to store anything like enough water to nearly double the average flow of a stream give an adequate return for the outlay? I venture to say it would, more particularly on such rivers as the North Esk, where an immense amount of capital has been sunk in mills on its banks. In the early days of the paper-making industry, the water-power was sufficient for the production; but as this gradually extended steam-engines were added, and water-power was relegated to the second place. As showing, however, that considerable store was set upon the water, most of the old water-wheels have been superseded by economical turbines.

From a series of measurements made by the author, the average quantity of water that can be got into the head-races at Roslin Powder-mills is 2000 cubic feet per minute during nine months of the year, for the remaining three months the average is 1500 cubic feet per minute; but even in summer we have seen 4000 cubic feet per minute passing down the stream, and in winter the water often rises 3 feet on the weir, or equal to 40,000 cubic feet per minute.

The total water-power on the Esk, which I have selected as being well known to this Society, is estimated at 1000 horse-power. Which at the low valuation of £10 per horse-power per annum (and it must be remembered it is available night and day) amounts to £10,000. Allow this to be simply doubled by storage, and we have an annual value of £20,000, half the annual gain, £5000, being enough to pay interest at 3 per cent. on £167,000, a sum sufficient to purchase land and form reservoirs of ample capacity for the purpose required.

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The annual loss from floods is very considerable, not to speak of the loss of power in existing plant from the rising of the water in the tail-races at the mills.

The destruction of property in the valley of the Esk by the memorable flood of August 1891 was enormous, and a few such losses would soon run into figures representing a large portion of the cost of such reservoirs.

We must look, then, for the future development of water-power in this country to some efficient means of storage at high levels, and the more extended use of high-pressure turbines.

A glance at the map of Scotland shows that many of our Scottish lakes, by their natural configuration, lend themselves to an easy adaptation for storage purposes, and where these do not exist, natural hollows are to be found which at a comparatively small cost could be converted into reservoirs. Land is of little value in such districts, but the time will come when the possessor of land, with a stream on it having a considerable fall, will derive therefrom a large and perpetual income.

Before the introduction of the turbine into this country forty years ago, ordinary vertical water-wheels only were in use, and falls of 40 to 50 feet at most were capable of being worked, and this accounts for the greatest development of water-power taking place on the lower reaches of rivers where large volumes of water with comparatively low falls had to be dealt with.

The introduction of the modern high-pressure turbine has changed all this, and enables direct falls up to 1000 feet to be worked with the greatest possible economy, both as to first cost and maintenance.

The introduction of steam-power for factory purposes has had the effect of concentrating those industries in districts where coal is cheap, crowding the population into large manufacturing towns, with all their attendant evils. It is hoped that an extended use of water-power combined with electrical transmission may have the opposite effect, and be the means of promoting village industries out of the immediate range of the coal-producing area.

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I may single out the small town of Pitlochrie, in Perthshire, as a case in point, where a most successful industry has been built up, all the machinery being driven by water.

Railways.—It must have been noticed by the most casual observer, that many of our main lines of railway follow the beds of streams, and it has occurred to the writer that they would form an excellent track for a main-pressure pipe-line for the production of power at stages all along the line. The cost of track forms a very large item in a line of pipe. Many of these lines of railway have a fall of 80 to 100 feet per mile, and this system combined with storage at the higher levels would provide a source of constant power for the use of factories and other works, to the direct benefit of railway companies, landed proprietors, and the community at large.

Numerous instances might be cited where this system could be carried out with economy, such as the main lines of the Caledonian and Highland Railways.

The use of steel riveted pipes would prevent all danger from bursting, as the working head could be so arranged as not to exceed 100 feet.

I have already mentioned that the greatest extension in water-power, as far as Scotland is concerned, will be in those parts of the country where a heavy rainfall takes place, combined with a ready means of storage, and a glance at the map will show that few countries are better adapted for the purpose. These places are at present out of the reach of existing centres of manufacture, although doubtless in time the establishment of power centres will have the effect of drawing towards them, with increased facilities of transit, a corresponding increase in local demands for power.

It is with the transmission of power to existing centres that we have now to deal.

There are four practical methods of doing this:—(1) Wire rope. (2) Hydraulic. (3) Compressed air. (4) Electricity.

For distances up to 500 yards, wire rope transmission is the most economical. At 1000 yards, wire rope and electricity are about equal, the hydraulic and compressed air systems being nearly double. Whereas at distances up to 5 miles the cost by electricity is only one-fifth of the other methods.

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The efficiency of compressed air transmission has been proved by Prof. Kennedy, who carried out an exhaustive series of experiments on the Popp system in Paris, and also from numerous tests in colliery work which have come under the author's own observation, not to exceed 30 per cent. Whereas there are numerous examples of electric transmission of over 65 per cent.

One of the most recent applications is that of an underground haulage plant at Abercanaid Colliery, South Wales, by Messrs Howell & Co., Limited. Here there is a generating plant at the top of the pit, and several hauling and pumping engines underground. The cables extend a mile underground. The first cost is only one-half of a compressed air plant, and the efficiency is between 60 and 70 per cent. At Messrs John Vipond & Co.'s mines, 500 gallons per minute is pumped 600 feet high; power transmitted over a mile.

For experience in long-distance transmission we have to fall back upon foreign practice, for as yet in this country we have no transmission over 5 miles for lighting, and we know of none over 3 miles for power.

At the Phœnix Gold-mines, New Zealand, 52 horse-power is carried a distance of 3 miles, through a cable No. 8 B.W.G., ·165 in diameter; the loss of power on the cable is 3 horse-power

At the present time on the Continent we hear of nine water-power transmission schemes in progress, aggregating 3000 horse-power, and these are being put down with the greatest confidence by the promoters that they shall be a commercial success. The system has been proved, and is now beyond the range of mere experiment.

The gigantic Niagara scheme is being carried out on the basis of at least three-quarters of the total power being conveyed distances of 20 to 100 miles, and a large amount is already contracted for at rates from £3 to £5 per horse-power per annum in the town of Buffalo, 20 miles off. This price, when compared with the price of steam or gas engines at from £9 to £10 per annum, must ultimately place the manufacturers of Buffalo in a very favourable position.

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If a water-power costs more than £4 to £5 per horse-power per annum, it will not pay to transmit that power.

The following table has been prepared by Messrs Crompton & Co., of Chelmsford, and is based on work actually carried out by them.

No.	Nature of Line.	No. of Motors.	Distance in Miles.	Working E.M.F.	B. Belt, Horse-Power required by Generator.	C. Loss in Line in Horse-Power.	D. Brake, Horse-Power delivered by Motor.	Efficiency of Transmission.	Approx. Cost of Plant Motive Power not included.
									£
1	OH	1	⅛	100	14¼	1¼	10	70	265
2	OH	1	1	500	67	6	50	74·6	1170
3	UG	1	1	500	67	6	50	74·6	1550
4	OH	1	1	500	74½	12	50	67·3	1070
5	UG	1	1	500	74½	12	50	67·3	1340
6	OH	10	1	500	75	6	50	66·6	1600
7	OH	1	5	1000	65½	4½	50	76·3	2840
8	OH	1	5	1000	74½	12½	50	67·1	1800
9	OH	1	5	1000	99	35	50	50·5	1630
10	OH	1	5	1500	65½	4½	50	76·3	1850
11	OH	1	5	1500	74½	12½	50	67·1	1380
12	OH	1	5	1500	99	35	50	50·5	1400
13	OH	1	20	3000	82	19	50	61	2740
14	OH	2	5	3000	800	75	600	75	8500
15	OH	2	5	3000	940	200	600	63·8	8000

OH means Overhead Line, and includes bare copper conductor, with a suitable supply of insulators, posts, guywires, &c.

UG means Undergrouud Line of heavy insulated copper cable, lead sheathed and protected.

In the preceding table, the first example speaks for itself. Examples 2 to 6 are 50 horse-power 1 mile installations. Nos. 2, 3, 4, and 5 are pairs, one overhead and the other underground. Nos. 2 and 3 have a loss of 6 horse-power on the line, and are very efficient, 74·6 of the power put into the generator being delivered at the motor as useful work. The efficiency is 74·6 per cent.: note this when comparing electricity with any other form of transmission. No. 2 conductor costs about one-fifth of the total cost of the plant; to gain other 3 horse-power, it would be necessary to spend £200, and nearly double the sectional area of cable. Again, if we agree to lose 12 horse-power by halving the line, and save £100, we have to take into account the cost of producing the 6 horse-power. Where water-power is very cheap, it will pay to use a light cable and lose some power on the

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way. The most economical size of cable depends on what we can afford to lose.

No. 6 shows the increased cost if the power is taken off by small motors instead of one large one.

Nos. 7, 8, and 9 are long-distance schemes, with a higher E.M.F.

No. 8 is probably the best arrangement, as to reduce the loss to 4½ horse-power it is necessary to spend £1000 more on the line—as in No. 7.

No. 9 is as far the other way, as what we save in the line causes an excessive loss in power, and the generator costs more, having to be more powerful to overcome the extra resistance.

No. 8 is made up as follows:—

Generator and motor, foundations, &c.,	£820
Regulating apparatus, &c., . . .	55
Copper wire of line, ...	815
Sundries, insulators, &c., . . .	90
	£1800

No. 13 shows that for less than £3000, 50 horse-power can be transmitted 20 miles; the cost of copper conductor is nearly half the total, and if the percentage of loss were increased, a considerable saving in cost could be effected.

Nos. 14 and 15. When the power is over 300 horse-power, it is advisable to have two motors; this reduces the risk, and the cost is much the same as having one large machine.

From what we have shown, it is clear that electricity is the only means of transmitting power economically over considerable distances.

The town of Carlow in Ireland is lighted with electricity, and is an interesting example of long-distance transmission. The water-power is at Milford, on the river Barrow, 5½ miles from the town. There are two turbines of 50 horse-power each, with a fall of 7 feet; these drive an alternating current dynamo generating current at 2300 volts, this is conveyed by underground cables. The high-pressure mains are led into a switch-house at Carlow, and divide into three circuits carried on posts

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overhead. There is also a complete network of low tension mains extending through 5 miles of streets.

Transformers are fixed on the posts themselves, and feed into the low-tension network. This arrangement is simple and effective, and the cheapest that could be devised.

The commercial success of this enterprise is of considerable public importance, as Carlow is not a wealthy town, and may be taken as a fair average representative of many hundreds of similar towns. The whole of the water-power arrangements, turbines, &c., were designed and constructed by the author.

After hearing so much about what is being done abroad, it is pleasant to report that some progress has been made in various parts of Scotland. In the county of Inverness there has been erected during the past two years fourteen electric light installations, with water as the motive power. One of these, carried out by the author at Loch Rosque Lodge, Ross-shire, possesses some interest from the fact that a fall of 650 feet is applied to the turbine, and as far as is known, this is the highest fall applied to power purposes in the kingdom. The water is taken from a mountain stream, and a storage of 20,000 cubic feet provided by a dam formed in a natural hollow. The water is conveyed partly in an open cutting and partly by fire-clay pipes for half a mile to a settling tank 650 feet above the turbine, to which it is carried by riveted steel pipes 600 yards in length; 35 horse-power is obtained. The total cost of the hydraulic part of the apparatus was £700. Allowing 5 per cent. interest, and 5 per cent. depreciation, the cost is only £2 per horse-power per annum. The cost for attendance is trifling.

Another water-power electric light scheme has been carried out by the author at Duntreath Castle, Stirlingshire. Here a fall of 300 feet is obtained, and with a high-pressure turbine produces 25 horse-power. A small dam to store 40,000 cubic feet is provided. The total cost is about £800, making the annual cost £2 to £3 per horse-power per annum.

The only electric railway in Scotland is a private line, 1½ miles long, on the Carstairs estate. It extends from Carstairs House to Carstairs Junction on the Caledonian Railway system. The gauge of the line is 30 inches.

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The source of power is a waterfall 3 miles distant. The turbine, which has a working head of 40 feet, drives a series dynamo giving 40 volts 40 ampères, or 20 horse-power. Besides working the railway, this turbine and dynamo are used to light the house, saw wood, and drive farm machinery.

There are several small towns in Scotland at the present time contemplating the introduction of electric lighting by water-power, and in a country so highly favoured by nature as ours for such a purpose, it will be strange if native enterprise is wanting to carry these schemes to a successful issue.

On Improved Turbines for the Utilisation of Water for Power. By JOHN RITCHIE, C.E., Edinburgh. (With Plates.)*

In the first portion of the communication on the "Utilisation of Water for Power" made to this Society, the subject was treated generally. The sources of power and examples of the successful application of such in various parts of the world were given. In this paper I shall describe some of the means through which the power of water is applied.

In order to transform the weight of water into energy, it is necessary that the water should fall through a certain space, and to get this fall is the first object of the engineer. In streams, this is generally obtained by the construction of a weir, the water being carried to the motor by an open cutting, or channel, or by a pipe. For falls up to 10 feet it is usual to have an open cutting or an earthenware pipe, and in falls over 10 or 12 feet to use an iron pipe.

As the use of the ordinary vertical water-wheel is, except for very special purposes, all but superseded by some form of turbine, I will confine my remarks to the latter machine.

Where the fall is limited, the proper construction of the inlet channel, or head-race, is of great importance, if full advantage is to be taken of it. The sectional area should be

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* Read before the Society, 10th April 1893.

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Fig. A.—PRESSURE TURBINE in open Iron Flume.
SUITABLE FOR A LOW FALL.

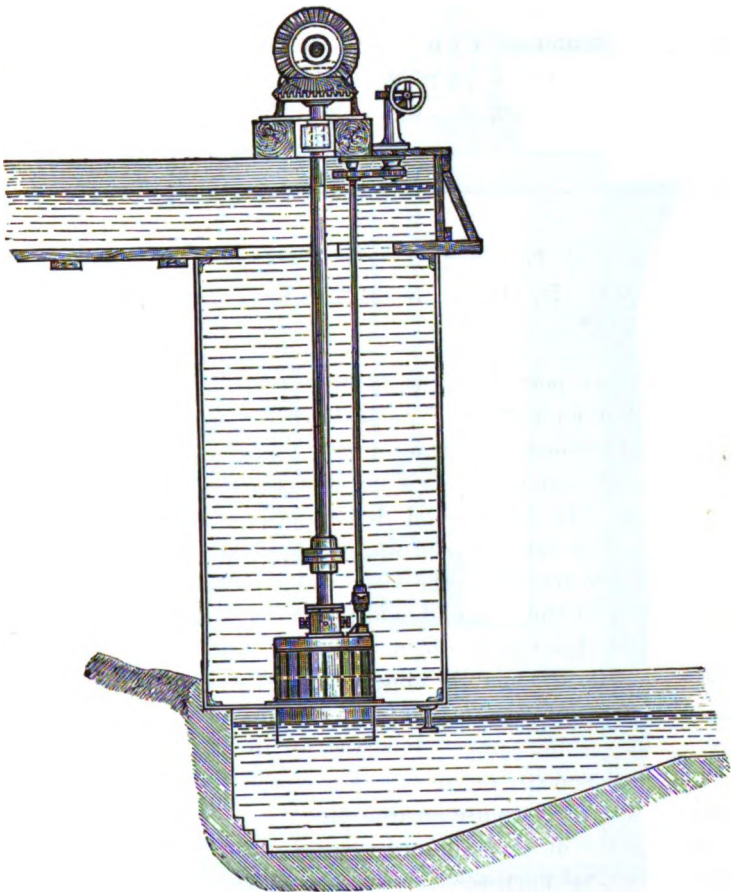

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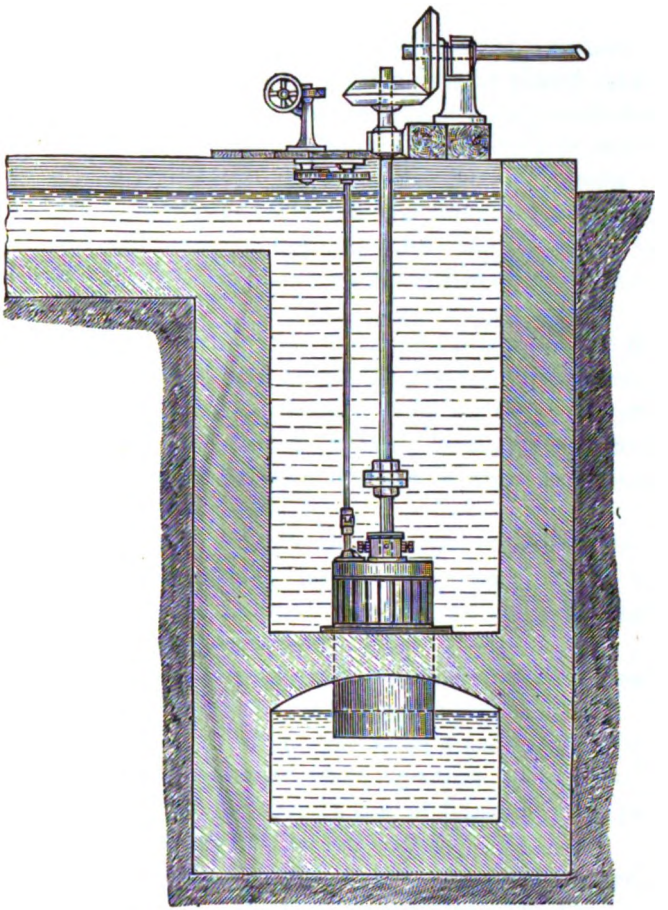
Fig. B.—PRESSURE TURBINE in open Brick Flume.
SUITABLE FOR A LOW FALL.



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so proportioned that a speed of not more than 2 feet per second is attained by the flowing water; where a greater fall can be got 3 feet per second is a usual speed. The same remarks apply to the outlet channels or tail-races, the object being to bring the water to the motor, and allow it to escape from it, after having done its work, with the lowest possible velocity.

Fig. A illustrates the usual method of fixing a turbine on a low fall. The flume, or well, in which it is placed must be large enough to allow of inspection of the wheel, which, unless there are special reasons to the contrary, should be set close down to the tail water. In falls of 4 feet and under it is preferable to have the bottom of the flume 12 to 18 inches below the tail water, and in all cases the outlet, or draft pipe, must dip into the water several inches when the turbine is at work.

If the stream is subject to floods, the bottom of the flume may be kept several feet above the low level tail water, and the draft tube made long enough to be sealed at the lowest level of the stream, so that the working head may be increased in the dry season, and every advantage taken of the available water.

Here we have an illustration of the superiority of the turbine over the ordinary vertical water-wheel, which must be set some distance above tail water, so as not to be stopped with even moderate floods.

A turbine may be worked drowned, giving off a proportionately less power according to the diminished fall.

The head-race to a turbine should be so constructed (if the cost be not excessive) that advantage may be taken of the rise on the crown of the weir in case of floods, so as to partly compensate for the rise of the tail water.

It is sometimes less costly to make a cutting or culvert for the tail water, and bring in the head water on the general level of the ground, as shown on fig. B.

The flumes may be of timber, iron, or brickwork. The material used must depend on the situation and other circumstances.

For falls of over 10 or 12 feet it is usual to place the

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turbine in an iron case, and convey the water to it by a pipe. Where the pipe is of considerable length, it is usual to arrange it so that fire-clay pipes may be used until a point is reached when the pressure becomes too great for this class of pipes. An iron pipe must then be used; 5 to 8 feet of head may be put on a good fire-clay pipe if properly laid and jointed.

In determining the diameters of pipes for conveying water to turbines, we must be guided by the laws which determine the loss of head from friction in pipes. The neglect of this from ignorance or carelessness has often caused great annoyance and loss. A case of this kind was recently brought under the notice of the author. A turbine had been at work for several years under a head of 60 feet, but did not give out the power that might have been expected from the fall and quantity of water. A pressure gauge was put on the pipe at its lower end. On starting the turbine without load the pressure fell to 23 lbs. per □″, and with full load to 17 lbs., equivalent to a head of 40 feet, showing that 20 feet of head was lost from friction in the pipe owing to its small diameter. Another pipe was therefore laid alongside the existing one, and on a test being made a pressure of 23½ lbs. was maintained at full load, equal to a head of 55 feet, showing only a loss of 5 feet of head, and producing 3 horse-power more on the turbine with the same quantity of water as before the alteration.

Fig. C shows the friction curve on a pipe 6 inches in diameter and a mile in length.

This pipe was put in a few years ago for a water-supply and fire service in connection with a mansion-house, and is fed from a small mountain lake. It was required to find out the greatest power that could be produced by fixing a turbine at the lower end of the pipe. There is a head of 410 feet.

I fixed a pressure gauge at the lowest part of the pipe, and took a series of readings, with an increase each time of 5 cubic feet up to 60 cubic feet, noting the corresponding fall in pressure. On working this out, it is found that the maximum carrying capacity of the pipe to produce the greatest power is 55 cubic feet per minute, with a head reduced by friction to 281 feet, which gives 20 horse-power.

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This line of pipe is now being adapted to drive a turbine and dynamo for an electric lighting scheme of 200 lamps.

Up to 8 or 9 inches diameter cast-iron pipes are most suitable for pressures under 400 feet head; above this size the pipes become very heavy; and the cost of laying, especially on a steep ascent, is considerable. It is then preferable to use riveted steel pipes; these are only one-fifth of the weight of cast-iron, and two men can carry a 20-feet length of 6-inch pipe. There is absolute safety against bursting; and, as far as can be proved as yet, steel pipes are, when properly coated, as durable as cast-iron.

Turbines.

Having thus briefly described the method of bringing the water to the turbines, let us consider now the construction of these, and the principles upon which they act.

The energy of falling water is utilised in a turbine, by causing it to enter the spaces formed by curved vanes or buckets, as nearly as possible at right angles to the radii of the wheel, and discharging it in an opposite direction to that of rotation.

A turbine consists of a disc or cone to which are attached the buckets at equal distances round the circumference. The disc is fixed to a shaft, through which the power is transmitted. For the sake of simplifying description, turbines may be divided into *four classes*:—Outward-flow, downward-flow, inward-flow, and mixed-flow, as regards the direction of the water through the wheel; and into *two systems* as regards the action of the water relatively to the wheel, viz., pressure or reaction and impulse turbines.

It is necessary to remark here, however, that it is hardly possible to make more than a general division of system, as many modern turbines partake of the nature of both, part of the work being done by impulse, and the remainder by reaction. In *outward-flow* turbines the water is admitted at the centre of the wheel, and discharged at the circumference. In *downward-flow* it enters the buckets at the upper side of the wheel, and is discharged at the lower side. *Inward-flow,*

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the water enters at the circumference, and is discharged at the centre. *Mixed-flow*, the water enters at the circumference, and is discharged partly at the centre and partly below.

All these wheels have some kind of guides for directing the water into their buckets.

To obtain the highest efficiency from pressure or reaction turbines, it is necessary that all the passages be completely filled, and most of these turbines are designed so that they may be used with a suction-tube, and are capable of being placed above the tail water.

In impulse turbines it is not necessary that the buckets or passages through the wheel should be filled with water, but partially filled with air. Impulse turbines must be set clear of tail water.

We will now describe the different classes a little more in detail :—

Outward-flow Turbines.

The Fourneyron turbine, named after its inventor, is the best example of an outward-discharge turbine, and was really the first modern turbine, being invented in the year 1823, and put into actual use a few years later. The efficiency of this purely-reaction turbine, with the maximum supply of water, is 80 per cent. It is, however, costly; and, owing to the smallness of the passages, is apt to become choked.

Very few Fourneyron turbines are now made in this country, and the interest in it is chiefly historical, from the part it has played during the past sixty years in the more extended use of turbines.

Downward-flow Turbines.

These are sometimes called Jonval turbines, from the name of the engineer who first constructed them. Many of these wheels are used on the Continent of Europe, where they seem to be preferred to inward or mixed flow turbines.

The construction consists of a series of guides formed by radial divisions fixed between two rings, and placed above the

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wheel, which is formed of two rings having radial buckets fixed between them. The inner ring has arms and a boss, so as to connect to the shaft.

This turbine may be worked with a suction-tube, and is superior in every way to the outward flow. Its good points have been adopted by the designers of mixed-flow turbines.

Inward-flow Turbines.

The vortex turbine of Professor James Thomson was the earliest practical development of this class, and the parent of the now numerous types of inward-flow turbines. Different arrangements of gates have been adopted; the usual one consists of four movable guide-vanes turning on pivots near the inner point, so that by closing the outer end the water is cut off. The principal objection to this method is that, for varying amounts of opening, the angle of the entering water is altered from the best position, and no provision is made in the wheel for directing the water as it leaves the buckets, which, consequently, has to find its way out the best way it can.

Mixed-flow Turbines.

These defects in the ordinary inward-flow turbine led to the introduction of the mixed-flow turbine. The water flows inwards, and then, by the peculiar configuration of the bucket, downwards, and also in a nearly horizontal direction opposite to the plane of rotation. (We are here speaking of a turbine with a vertical shaft.)

This enables a greater discharge area to be obtained with a given diameter of wheel, and the water, instead of having to find its way from the centre of the wheel unguided, is gradually turned downwards by the conical centre of the wheel, and by the curve on the buckets, and leaves them at as low an angle as is consistent with the details of construction. The conical centre has the effect of relieving the pressure on the footstep by the deflection of the water when passing through the wheel from a horizontal to a vertical direction.

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A pressure or reaction turbine can only work at its maximum efficiency when all the passages are full, and all systems of regulation more or less reduce the efficiency. We are here brought face to face with the theory of the pressure and reaction turbine. Many minute mathematical investigations have been made into the theory of turbines, but none of these are sufficient to explain the high efficiency obtained from turbines which are not constructed at all on the lines laid down by mathematicians. Nearly all writers on turbines have laid it down as a law that the water must enter without shock—that is, the circumferential velocity of the wheel where it receives the water, and the angular velocity of the entering water must be equal. When this is the case there is no impulse. In the old Fourneyron, the water was received on to the wheel in such a way that the entire power was produced by the deviation of the water through the wheel, or, in fact, depended entirely on the reaction. In modern mixed-flow turbines this is not the case. The speed of the wheel is so determined in relation to the velocity of the entering water that the water acts by impulse on the outer portion of the bucket, and by reaction on the inner portion (fig. D), and the shape of the bucket may be designed so that the relative proportions of impulse and reaction may be varied.

In determining the action of water on a vane, the relative velocity and the counteracting resistance due to centrifugal force must be taken into consideration. This materially affects the shape of the bucket, not so much in the discharge angles, which must be kept as low as possible in all cases, but in the relation between the inner and outer diameters and in the length of the vane. The practice, then, of many American turbine builders of making wheels of a given diameter, all from one pattern in stock sizes, is not to be commended. One wheel may by good fortune come in all right, and give good results, but another may be entirely unsuited for its work.

In determining the angle at which the water leaves the guides, we are restricted by the necessary space occupied by these guides themselves, and the number of ports we adopt. If we have too many ports and buckets, we unnecessarily

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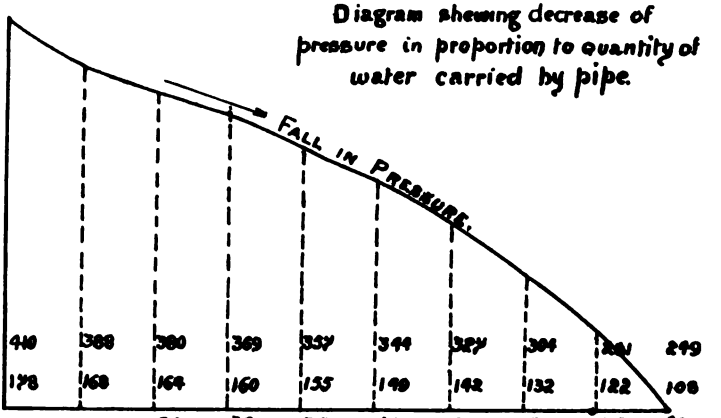
Diagram shewing decrease of pressure in proportion to quantity of water carried by pipe.
FALL IN PRESSURE.
FEET HEAD
LBS per □IN
CUB. FT.
H.P.
410 388 380 369 357 344 327 304 284 249
178 168 164 160 155 149 142 132 122 108
20 25 30 35 40 45 50 55 60
10 12·3 14·3 15·4 17·8 19 19·7 20 19·4

FIG. C.

Friction Curve on 6" Pipe one mile long.

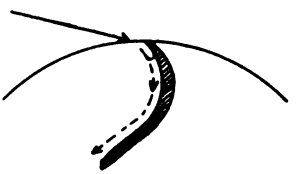

FIG. D. Shewing action of water on bucket.

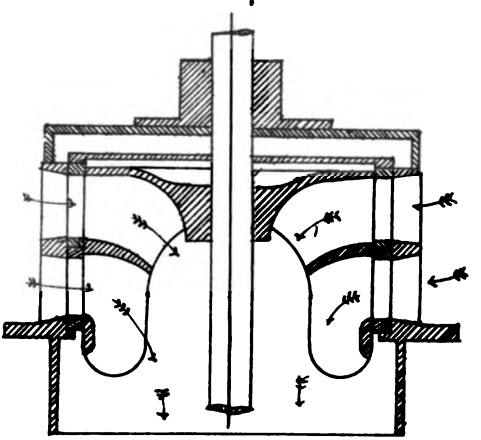

FIG H.

Ritchie's Patent Turbine with Double Gate.

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increase the friction and reduce the efficiency; and if too few ports and buckets, the stream of water is apt to deviate from the best line of direction through the wheel. An angle of 15° to the tangent of the inner diameter of guide circle is as low as we can adopt in practice. Owing to the smallness of the inner diameter of buckets, the mean angle of discharge cannot be made less than 16°, and the lower part of the bucket a mean angle of 17°. The water is thus turned through 147°.

From what we have stated about the part played by the water on the outer part of the wheel buckets by the impulse, provided always, that the speed is properly proportioned for that purpose, it follows that the best method of regulating the water to the wheel is one which will maintain a uniform mean angle of entrance, and at the same time form a true contracted vane, so that the energy of the water may be kept up until the wheel bucket is reached.

Very few of the many forms of regulating apparatus to mixed-flow turbines conform to this important rule. Hence, the percentage of efficiency falls rapidly whenever part of the supply is cut off.

The author, when taking up the systematic manufacture of turbines, early adopted the mixed-flow type as being superior to all others both in efficiency and reduced size and weight in proportion to power, and also in first cost; and an inside cylindrical gate, for simplicity, freedom from wear, and non-liability to get out of order, as the means of regulating the water to the wheel. He soon discovered, however, that this form of gate, though possessing many excellent features, had a defect which will be seen in fig. E.

This gate, as ordinarily constructed, is a single casting with ports formed in it to coincide with those in the guide ring, which is bored out to receive it, the inner surface of the gate being also bored to receive the wheel. It will be observed (see fig. E) that when the gate is full open the proper form of contracted vane is complied with, but when only partially open the orifice is first contracted, and the water so admitted has to pass into an enlarged space where it has room to expand and deviate from the proper line of direction, and

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owing to the increased area its velocity is diminished, and the impulse or action on the outer portion of the bucket is much lessened. To obviate this defect I introduce fixed guides between the bars of the gate, so that the advancing side of the bar on the gate moves to and from the fixed guide blade, still maintaining the proper form of channel for the entering water, however more or less the gate may be opened (fig. F).

The gate is moved from opposite sides by pinions gearing into short segments of racks fixed to the upper end of the gate. This arrangement is found to be a great improvement on that of only one rack and pinion. The friction is so slight that the gate of even a very large turbine may be placed under the control of a governor. The introduction of the guides through the gate has increased the efficiency at part gate to a very marked extent.

It is often found to be a great convenience to have a turbine with a horizontal shaft, and the inside cylindrical gate is found to be the most suitable for this type of turbine, and in practice works equally well horizontal or vertical. Fig. G represents a turbine with a horizontal shaft.

In order still further to increase the efficiency in the case of turbines which occasionally work with say one-half of the maximum supply. I make the gate in two rings, one above the other (see fig. H), each fitted with gearing for opening and closing, so that one may be shut entirely off when the supply of water is low, and the other may be worked full open.

There is a division in the buckets to correspond with the blind space of gate rings. The water entering the upper gate passes down the centre of the wheel, and that from the lower one is discharged by the under side of the buckets. This arrangement is nearly perfect as a regulator. These improvements in turbine gates have been patented by the author, and the combination is known as the Waverley Turbine.

The best proportion between inflow and outflow areas for mixed-flow turbines is found to be an excess of 15 to 20 per cent. in the discharge.

It will be readily understood that in order to reduce the friction in the passages, the surfaces acted on by the water should be as smooth as possible.

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Diagram of ordinary cylindrical turbine gate.

FIG. E.

Diagram of Ritchie's Patent Cylindrical Gate with projecting guides.

FIG. F.

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When the interior passages of the wheel are formed by sand cores and the wheel cast all in one piece, it is not possible to get a perfectly smooth surface. I prefer to cast all the buckets by themselves of a special mixture of iror which gives lightness and strength. After being carefully smoothed they are fitted into their proper places in a circular box, accurately spaced for the discharge area, and the whole rammed up with sand, a space being left for the ring round the buckets and for the central cone. The whole is now put into the mould and closed, a large quantity of metal poured into the mould, and allowed to flow through until the ends of the buckets exposed to the metal are near the point of fusion; the outlet is then plugged, and the mould fills up.

This method ensures a strong wheel, with a smoother surface than can be obtained by any other method.

A turbine of the pressure and reaction type may be placed any height above tail water up to 30 feet, a suction pipe being fitted on the discharge side of the wheel and made to dip into the tail water. In practice, however, owing to the danger of leakage of air from the joints, the suction pipe is kept as short as possible.

Impulse Turbines.

We have already pointed out that mixed-flow turbines were designed so that part of the work at least was performed by impulse. We have now to deal with a system of turbine which acts entirely by impulse. The water passing through the buckets of an impulse turbine must not fill them, and the interior of the bucket is in communication with the atmosphere. In order to make this certain, ventilating openings are formed in the sides of the wheel to allow the air to be driven out of the bucket by the impact of the water, and to enter it again when free. It is not necessary in an impulse turbine that the water be admitted to the whole of the buckets of the wheel, as in a pressure turbine; the wheel may, therefore, be made larger in diameter in proportion to its capacity than a pressure turbine. This is a very great advantage where a high fall and a small quantity of water has to be dealt with. The water in this class of turbine is

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admitted to a few of the buckets of the wheel, usually not more than six or eight, and can be regulated to any extent without affecting the efficiency. The ports are closed one after the other by an internal slide; each port when open works with its full supply, and this arrangement is really perfect for variable supplies. A suction tube cannot be used with this type of turbine, as it must have a free delivery above tail water. It is, therefore, not suitable for low falls, or where a great variation in the level of the tail water takes place. Fig. K represents a Girard or impulse turbine with a horizontal shaft, as constructed by the author for falls of 50 feet and upwards.

The velocity of the water issuing from the guide passages of an impulse turbine is that due to the head, less the friction in the passages; and the speed of the wheel may be varied or raised to a greater extent from what may be called the *best* speed than is the case with pressure turbines, without materially reducing the efficiency. I have found the best circumferential speed of Girard turbines to be ·45 of the theoretical velocity due to the head.

It will be observed in the diagram of Girard wheel (fig. L), that the width of the wheel is increased at the circumference by extending the ports or passages as they near the point of discharge. The object of this is to cause the water to flow in a thin stream along the hollow side of bucket and prevent choking at the outlet. The buckets are turned backwards in much the same way as in pressure turbines, so as to obtain a low angle of discharge, and reduce the relative velocity of the issuing water to that of the wheel.

In an outward-flow wheel this relative velocity is increased during the passage of the water through the buckets, whereas in an inward-flow wheel it is diminished. There are, however, so many compensating advantages in the Girard impulse wheel, more immediately connected with the regulating apparatus, that the small loss due to the increase of velocity is more than made up.

The Girard turbine is specially applicable to such falls as may be found in many parts of Scotland, where comparatively small streams may be made to yield a very considerable power.

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Fig. G.—HORIZONTAL PRESSURE TURBINE.

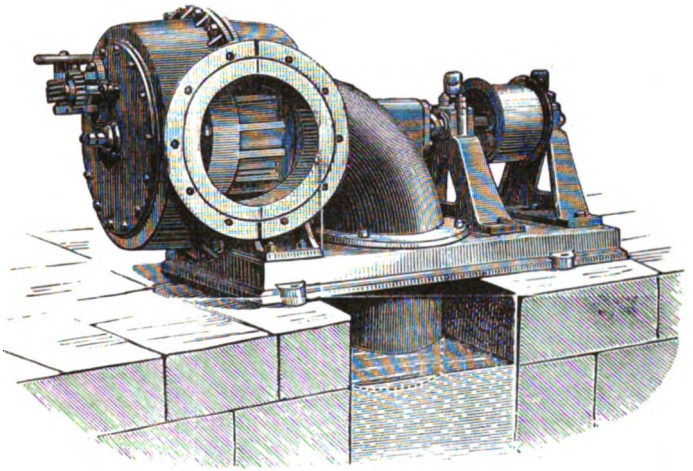

Fig. K.—HORIZONTAL IMPULSE TURBINE,
SYSTEM "GIRARD."

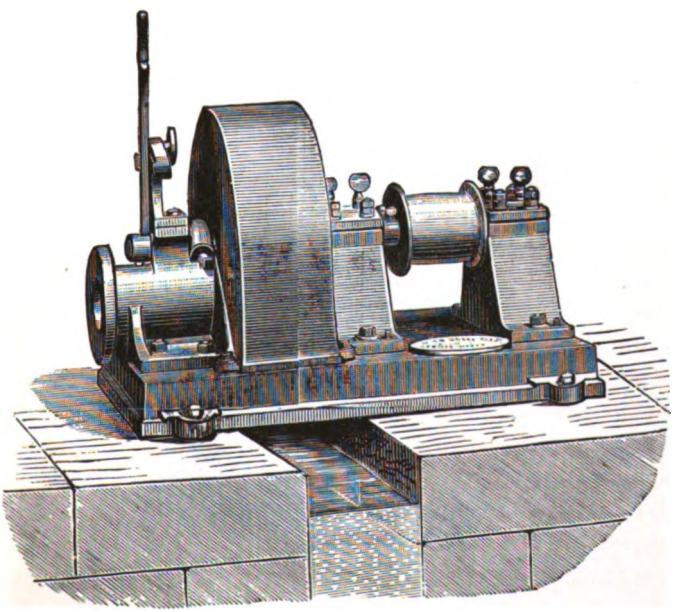

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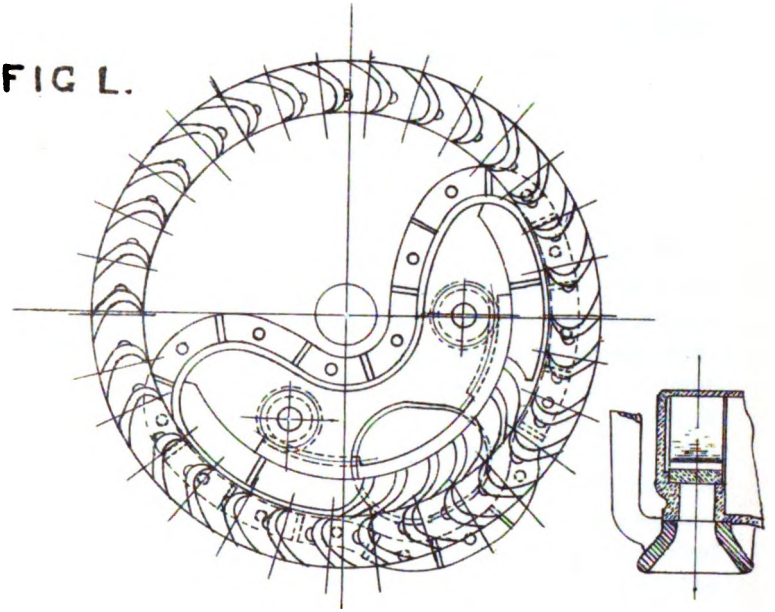
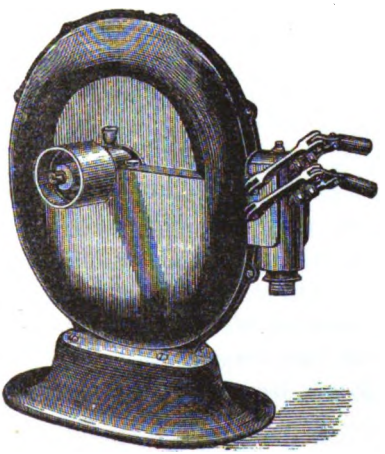
FIG L.



Section of Impulse Turbine, system Girard, shewing guide ports, double slide, and wheel buckets.

FIG. M.



Jet Water Motor.

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MACLENZIE & STURRIE LT.

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The turbine fig. L will produce 25 horse-power; it is fitted up in connection with an electric lighting installation of 250 lamps. The working head is 300 feet. The stream from which it is supplied falls in summer to 20 cubic feet per minute. A small dam is formed in a hollow on the hillside to hold about 30,000 cubic feet, and sufficient water stored to run the turbine six hours in the driest season.

In selecting a turbine, it is not merely the one which gives the greatest power with the least quantity of water that is the best for all circumstances, the average conditions must be taken into account. For instance, take a stream, without any arrangement for storage, say, with a supply of 3000 cubic feet per minute for six months in the year, but which in summer falls to between 800 and 1000 cubic feet. If it is intended to utilise the winter supply to anything like the full extent, it would be better to have two turbines, one somewhat larger than the other, so that both may be worked by the full supply, and either one or the other take the summer supply, and in this way the greatest economy is obtained.

If only one turbine is used, it would be better to make it for, say, 2000 cubic feet only, and have it fitted with the double cylindrical gate already described, so that when the water falls to 1000 cubic feet, one of the gates could be entirely closed and the other worked full open, the turbine would then work at nearly the maximum efficiency, less the friction due to the extra weight of the moving parts.

A good pressure turbine will give 80 per cent. of the total power of the water at full supply, but even the very best turbines of this class fall below 60 per cent. with half water, unless fitted with a gate of the type described.

Various forms of rising and falling cylindrical gates are in use with ribs cast on the buckets to direct the water, but as these ribs do not entirely divide the buckets into two or more chambers, the water cannot be prevented from rising up and partially filling the bucket space, and the object intended is thus defeated.

The maximum efficiency of an impulse turbine is somewhat lower than a pressure turbine, but for variable quantities

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they are to be preferred. The efficiency ranges from 70 to 75 per cent., and is practically the same with even half the full supply.

Most of the writers on the subject of turbines have adopted certain theories which have been built up on the result of actual tests, but they have involved these theories with an unnecessary amount of mystery. This arises from the information as to the actual working of turbines being received at second hand, many of the writers not having either constructed turbines or tested them.

In designing turbines, the areas of the passages must be carefully proportioned for the quantity of water to be used under a given head, and the proportions between inlet and outlet areas accurately determined; all abrupt turns must be avoided, so that the water may glide through the buckets by easy curves. The angles of inlet and discharge must be made as low as possible. No hard and fast rule can be given for the number of buckets in the wheel, it is usual to have two or three more guide passages than buckets, this ensures a more continuous flow, as no two buckets have the same relative position to the guide passages.

Motors worked by a single circular jet of water do not come under the general name of turbines, but a special type of wheel of American origin, and known by the name of the "Pelton" wheel, deserves special notice. It consists of a number of double buckets attached to the rim of a wheel, the water is directed on to the wheel from a single nozzle; the buckets have a central division, curving outwards on each side, so that the jet on striking the bucket is split and turned right round by the inner curve of the bucket, leaving it at about an angle of 80° on either side of the wheel.

The Pelton wheel is only suitable for high falls, and we believe there are special situations where its use would be more advantageous than a high-pressure turbine. There is some difficulty in regulating it for variable supplies with economy; the ordinary method is by throttling the water by a valve, or by a deflecting nozzle allowing a portion of the water to pass the wheel. On the Pacific coast of America it is almost exclusively used in the mining districts.

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At the Chollar shaft in the Comstock mines there are six wheels at work under the extraordinary fall of 1680 feet, these drive dynamos, the power being transmitted 2000 feet to the stamping mill. The nozzles of these wheels are only $\frac{5}{8}$ inch diameter, and each gives out 125 horse-power.

The water is that discharged from several wheels on the surface, and is then conveyed down the shaft to these underground wheels, and escapes by a tunnel to the face of the mountain.

Very few Pelton wheels are at work in this country, but the author has constructed several for use in Russia and elsewhere. He has also made a great number of small jet motors (fig. M) on much the same lines as the Pelton wheel, many of these are at work where small supplies of water with a high fall can be obtained, driving light machinery. One is at work at Fordell Colliery, Fife. The water which collects in the tubbing of the shaft, and which formerly fell to the bottom to be pumped up in the usual way, is now collected and conveyed to the pit bottom in a pipe, and used through this motor to drive a fan for ventilating. There is a wide field for the application of such motors.

It is impossible, in the course of such a paper as this, to convey anything like a comprehensive description of turbines and their application, but sufficient has been said to illustrate the general principles on which they are constructed, and examples given of the most successful types, so that some idea may be formed of the important part these machines play in utilising the water-power of the world.

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On a Form of Wheatstone's Bridge adapted for Clinical and Physiological Research. By R. MILNE MURRAY, M.A., M.B., F.R.C.P.E.* (With Five Plates.)

As work proceeds in the departments of physiology and clinical medicine, there is a demand for more and more accurate methods of investigation. Methods and instruments which at one time may have been regarded as sufficiently reliable are now being discarded for others which are found to be more accurate and trustworthy.

The purpose I have had in view in devising the instruments, which I show to the Society to-night, is to take advantage of the beautiful and simple principle of the Wheatstone bridge, and to provide an arrangement of this nature which will, I think, render various investigations in the departments of science just referred to more easy and more accurate than heretofore.

The various parts of the apparatus are fixed to a slab of vulcanite 19 inches by 10 inches, which forms the cover of a mahogany box 4 inches deep.

I. *The Bridge.*

Towards the front margin of the vulcanite plate (Plate III.) is the platinum-silver wire, 10 inches long, which forms the adjustable ratios of the bridge. This rests on a scale, and is traversed by the jockey *c*, which can be slid along the guide rod *ef*, and which can be more accurately adjusted by the micrometer screw *d*.

On the other side of the scale are placed four coils, g', g'', g''', g'''', of 10, 10, 100, 1000 ohms respectively, beginning at the left-hand side. These form the resistances in the other arms of the bridge. The blocks of each of the contiguous coils are connected by thick copper straps underneath the vulcanite.

The binding screw *h* is connected to the end of the left-hand 10 ohm coil, and the binding screw h' is connected to

* Read before the Society, 27th February 1893.

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the end of the 1000 ohm coil, while the binding screw *j* is connected to the clamp *a*, holding the bridge wire, and the binding screw *j'* is connected to the clamp at *b*.

These respective pairs of binding screws, *hj* and *h'j'*, thus form gaps, into which any resistance can be inserted into the two arms of the bridge.

The unbalanced current from the bridge can be led off either into the galvanometer direct through the terminals *z*, *z'*, or into the primary of the induction coil *k*. As to which path it takes depends on the position of the switch *l*, according as it rests on *m* or *m'*. The ends of the secondary coil of *k* are connected to the terminals *nn'*. The galvanometer current is led off from the guide rod *ef* of the jockey, and from the strap connecting the two 10 ohm coils, so that the four arms of the bridge are made up by the two halves of the wire on the one side, the left-hand 10 ohm coil for the third arm and the other coils, 10, 100, and 1000 for the fourth arm.

II. *The Adjustment of the Battery Current.*

An essential condition of some of the purposes of the apparatus is, that the battery current be kept constant. (This, of course, does not apply to cases in which the zero method is used.)

The battery is connected to the terminals *o*, *o'*. The current passes from the terminal *o* to the terminals *p*, *p'*, to which is connected a galvanometer reading in milliampères. From *p'* it passes to the guide rod *q* of the jockey *r*, and through the piece of stretched wire to the clamp *s*, and thence to the coils *u*, *u'*, After traversing these or their plugs it passes through the tongues of the relay AA', and thence to the bridge at *b*. The other pole of the battery is connected to *o'*, and the current passes from this to the key *vw*, and thence to the other end of the bridge at *a*.

By this arrangement it is easy to keep the current in the bridge of constant strength. The current passing through the arms is read by the galvanometer at *pp'*. Let us suppose that at the commencement of the experiment the galvanometer is indicating 30 milliampères, while the jockey *r* is at the *t*

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end of the wire. It is a simple matter to keep the current constant all through the observation by sliding the jockey towards *s* as the battery weakens, in this way cutting out a corresponding amount of resistance.

Further, the coils *u* and *u'* may be also used to adjust the resistance in the circuit, by putting them in or out of the circuit as may be required.

For certain purposes, to be indicated below, it is necessary to interrupt periodically the current flowing through the bridge, and this is effected by the RELAY seen near the middle of the instrument; and shown in detail in Plate IV.

This is operated by an independent cell or battery connected at *xx'* (Plate III.). The current passes from *x*, through the key *y*, to one end of the magnet B (Plate IV.). After traversing the magnet it passes to the pillar and arm of the relay C, D, and thence to the contact pillar E, which last is connected to the terminal *x'* (Plate III.). When the current is thus completed, the magnet attracts the armature, which is fixed to the arm of the relay D.

This breaks contact at D, E, and the armature is pulled away by the spring. This, however, again makes contact at DE, and the up and down movement of the arm is kept up. But each time the armature is attracted to the magnet the end of the arm C is brought sharply up against the platinum contacts A'A', which project from the pillars AA, and in this way the bridge current is completed with each upward movement of the arm DC. The rate of this movement is regulated by the position of the ball upon the vertical wire. By means of the screw, the end C of the arm can be pressed up against the contacts A'A', and in this way the current from the battery may be kept steadily flowing through the bridge when that is required.

When the key *l* (Plate III.) is on the position *m*, the unbalanced current from the bridge will flow directly into the galvanometer connected with *z*, *z'*; when it is in the position *m*, the current will flow through the primary of the induction coil *k*, and produce induction currents in the secondary, the ends of which are connected to the terminal *nn'*, to which a telephone is attached.

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Use of the Apparatus.

1. The apparatus may be employed for all the ordinary purposes of a Wheatstone's bridge, *e.g.*, measuring the resistance of metallic conductors, &c. If desired, it can readily be arranged for measurements by Carey Foster's method, by introducing an additional pair of gaps between the battery attachments and the bridge wire, for proportional coils, and calibrating the wire.

2. For measuring the resistance of electrolytes by a modification of Kolrausch's method. For this purpose it might easily be arranged that by a suitable switch the induced current from the secondary coil *k* might be sent through the bridge, and the electrolyte connected at *hj*, the gap *h'j'* being closed by a copper strap, and the unknown resistance determined in terms of the resistance coils of 10, 100, or 1000 ohms, and the bridge wire by the formula:—

$$x = \frac{R \times a}{b},$$

where x = unknown resistance of electrolyte.
R = resistance of coils unplugged.
a = left-hand part of wire.
b = right-hand part of wire.

In the bridge, as arranged, I find it more convenient to use an independent induction coil, actuated by a single bichrome cell, the terminals of which coil are to be connected to *oo'*, while a telephone is connected to *zz'*, the key *l* being in the position *l, m*.

It is, as is well known, almost impossible to wind the coils so that no induction occurs in them, and, consequently, there is no part at which the jockey *c* can rest in which there is not some sound in the telephone; but it is quite easy to determine the length of wire in which the sound is least, and the middle point of this will, of course, give the null point in the bridge. The formula given above then applies.

This method can be readily used to determine the resistance of the urine, blood, milk, or other animal fluids, and also the

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resistance of the human body—a condition which seems to vary greatly in health and disease.

3. Various methods have been adopted by aurists in order to determine the acuteness of hearing. In cases of partial deafness it is very important in estimating the effect of treatment to determine more or less accurately the improvement in hearing, or the opposite, shown by the patient from day to day. The ordinary method consists in asking the patient to listen to the ticking of a watch held at a certain distance. Assuming that the watch ticks so loud that a person of normal hearing can detect the sound at 30 inches, we would express the hearing of a partially deaf person who can hear it at, say 10 inches, by the fraction of $\frac{10}{30}$.

It is obvious that this is a rough-and-ready method which may serve some purposes, but is certainly destitute of accuracy.

A more accurate and trustworthy method of determining the acuteness of hearing is available by means of this instrument.

Let the gaps *hj* and *h'j'* be closed by copper straps. Connect a telephone to *nn'*. Unplug the two 10 ohm coils. Set the relay working, and close the key *v*. Adjust the plugs and slide wire at the back of the instrument until, say, 50 milliampères of current is passing through the bridge. If the jockey C is now set to one side of the wire—say towards *a*—a loud clicking sound will be heard in the telephone. Slide the jockey to the right, and the sound in the telephone will gradually diminish. Continue until the sound disappears, and the distance of this point from the zero or middle point of the wire is a measure of the deficiency of the sensitivity of the ear under examination.

The telephone may be used in two ways:—

1. The instrument may be held in the hand of the patient, and pressed against the ear and the side of the head. In this way the sensitivity of the ear to sounds conducted through the skull may be determined.

2. The head may be rested against a rigid board fixed vertically, in which a hole about 3 inches in diameter has been cut, on the opposite side of which—say 2 inches away—

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the telephone has been hung. In this way the sensitiveness of the ear to sound conveyed through the air and into the outer meatus may be determined.

By such means the improvement, or the opposite, which a given case shows under treatment can be determined with accuracy.

3. In order to make certain that the person whose audition is under examination is really hearing the sound in the telephone up to the point he thinks he is, the observer can use the key *v*. This, on being depressed, breaks the circuit, and this may be done without the knowledge of the subject, and gives a ready means of detecting any misapprehension or illusion on his part.

4. The apparatus affords a ready means of adjusting the strengths of galvanic and induced currents for clinical treatment or diagnosis, and for physiological observation.

Thus, suppose it is desired to determine the comparative excitability of two nerves to a galvanic stimulus, connect the stimulating electrodes applied to the nerve at *zz'*, close the gaps *hj* and *h'j'*, and unplug the two 10 ohm coils. When the jockey *c* is at zero, no current will pass out of the bridge when the relay is started; but on moving the jockey to one or other side, a gradually increasing current will traverse the nerve, and the amount required to produce the effect may be easily determined. The second specimen can be dealt with in the same way, and the difference of current strength required to produce the same effect accurately determined.

If the response to induced stimuli is to be ascertained, the nerves can be successively connected to the terminals *nn'*, and the slider of the bridge used in the same manner to adjust the strength of current passing at each movement of the relay through the primary of the coil *k*.

By unplugging the 10 ohm coil in the left and the 100 ohm in the right, the zero point on the wire will be shifted near to the left end of the wire, and a greater range of current strength made available. This device, which I have already described in connection with an instrument shown to the Society in 1891, is meant to replace the clumsy and by no

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means reliable method of regulating the strength of these stimuli by altering the distance between the primary and secondary coils of an induction machine.

5. This instrument is further designed in the hope that it may render comparatively easy the application of the principle employed by Langley in his "Bolometer" as a means of delicate thermometry in physiological and clinical research.

The principle depends on the fact that the resistance of a metallic wire rises with the temperature, and that within wide limits.

Callendar has proved by a careful research that for pure platinum the degree of accuracy with which temperature variations can be determined by this means is very great. Besides many physical applications, it has been employed by Rolleston in a research into the question of heat changes accompanying the action of nerves. But I am convinced that a wide field exists for this method in many clinical and physiological inquiries.

The arrangement required is sufficiently simple, and permits of almost any variation. For example, gap *h'j'* should be closed with a coil of about 1 ohm resistance. A piece of ·005 platinum wire, about 2 inches long, is soldered to the ends of the thick copper wire, passing through a cork. The platinum may be coiled into a convenient spiral, and the whole may be protected by a glass tube. Flexible leads connect the copper wire to the gap *hj*, and a delicate galvanometer of about 1 ohm resistance is connected to *zz'*. With the tube in water at the ordinary temperature the bridge will balance about the middle of the wire. Now, a very small variation of the temperature of the water will, by altering the temperature of the wire, cause variation of its resistance, and a consequent deflection of the galvanometer.

The delicacy of the apparatus may be illustrated in a variety of ways. Thus, if a glass rod moistened in sulphuric acid is introduced into about 4 ounces of water surrounding the tube, the heat of combination will be sufficient to give a deflection of several hundred millimetres. Again, if a few crystals of common salt are added to a similar quantity of water, the loss of heat in solution will be shown in the same way.

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The shape and disposition of the platinum thermometer may be modified so as to adapt it to almost any position or method of observation.

Further, the arrangement can readily be made a differential one. Thus, two pieces of platinum, cut from the same specimen of wire, may be inserted—one into each gap, *hj* and *h'j'*. Both having nearly the same resistance, the bridge will balance, when they are at the same temperature, at nearly the middle part of the scale. Both thermometers having the same coefficient of temperature, the effect on the galvanometer would at once indicate any difference of temperature to which they might be subjected. Thus, if one of the thermometers were placed in the mouth and the other in the armpit, we should have a ready means of comparing the temperature of the inside and outside of the human body. Similarly the temperature of any two parts of the body might be compared.

The surface temperature is known to vary considerably in certain diseased conditions, and it is of importance to determine these variations from time to time. I have found that a convenient method of arranging the platinum resistance for surface observations is to make two little flat spirals, lay them each between two cover-glasses, and dip the whole into a solution of shellac in spirit. When dry they may be attached to the surfaces to be observed by means of sticking-plaster, and then connected to the bridge.

Again, the temperature change, as the result of muscular action, may be studied by hanging a frog's muscle in the middle of a thin glass tube of sufficient diameter to allow it to hang and contract within it, but without touching the sides of the tube. Round the outside of the tube is coiled a platinum thermometer, and the whole is guarded from outside influence by another tube of glass, paper, or vulcanite. In such an arrangement two or three twitches of the muscle will deflect the spot over several divisions.

Such examples will indicate how easy it is to adapt this arrangement for a variety of purposes in physiological and clinical thermometry.

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On an Astatic Galvanometer with Interchangeable Coils.

By R. Milne Murray, M.A., M.B., F.R.C.P.E.*

The special features of the galvanometer is the way in which the coils are fixed and connected together, so that their removal and replacement by others is a very simple and safe procedure.

The coils are wound in boxes in the ordinary way.

To the faces of these boxes are attached two brass lugs, in each of which is a vertical slot *aa* (Plate V.)

The ends of the wire come through the front of the box, and are joined to two copper straps which project from the lower margin of the box *bb*. These are likewise slotted.

The coils are supported by the lugs *aa*, which are clamped to the ends of short horizontal arms carried on pillars supported on the vulcanite base of the instrument. When they are dropped into position, the projecting straps *bb* also fall in between the jaws of a pair of small horizontal clamps also fixed to the base of the instrument. These clamps are connected to the terminals of the galvanometer, so that the coils are properly connected to their respective terminals by the mere act of putting them in position. It will then be seen that, in order to remove one coil and insert another, it is only necessary to slacken the clamping screws at *aa* and *bb*, lift the coil vertically to clear the slots, and then remove it; the other coil can then be as easily dropped into its place, and all connections secured by simply tightening the clamps.

The inconvenience and risk of having to fasten and unfasten loose terminal wires is thus always avoided and good contact at the junctions secured.

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* Read before the Society, 27th February 1893.

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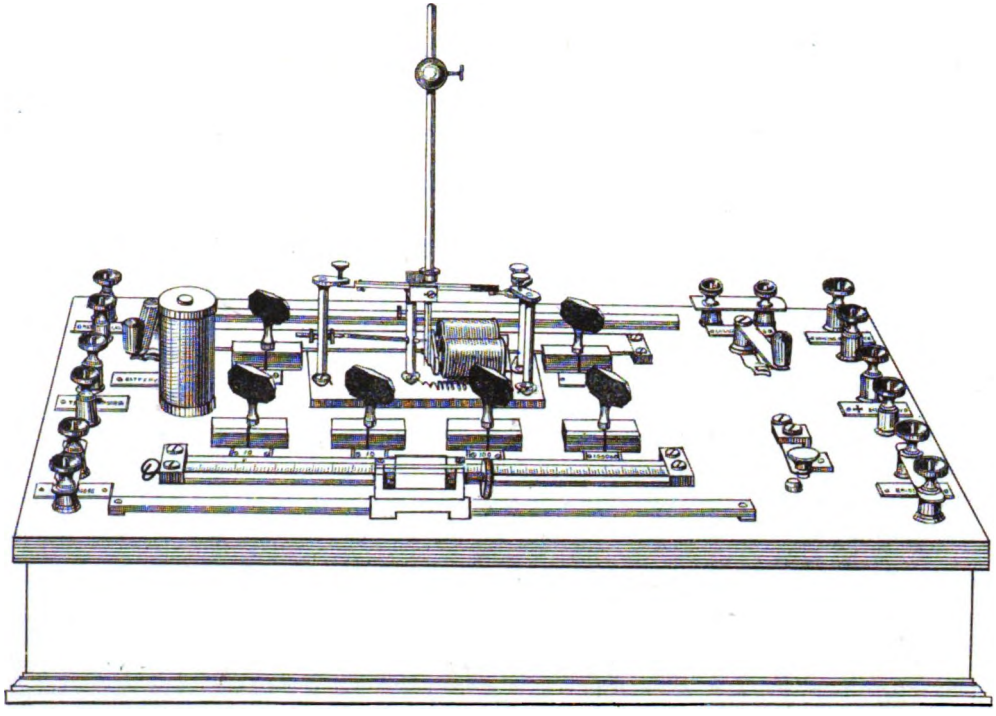

GENERAL VIEW OF BRIDGE FROM FRONT.

J. T. MURRAY

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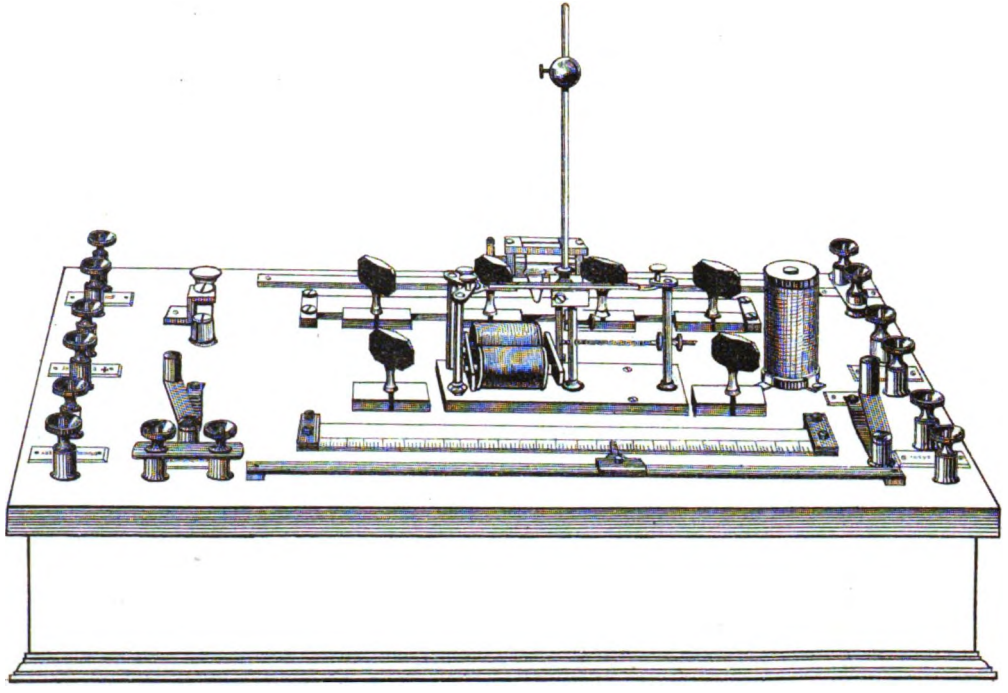

GENERAL VIEW OF BRIDGE FROM BACK.

J.T. MURRAY

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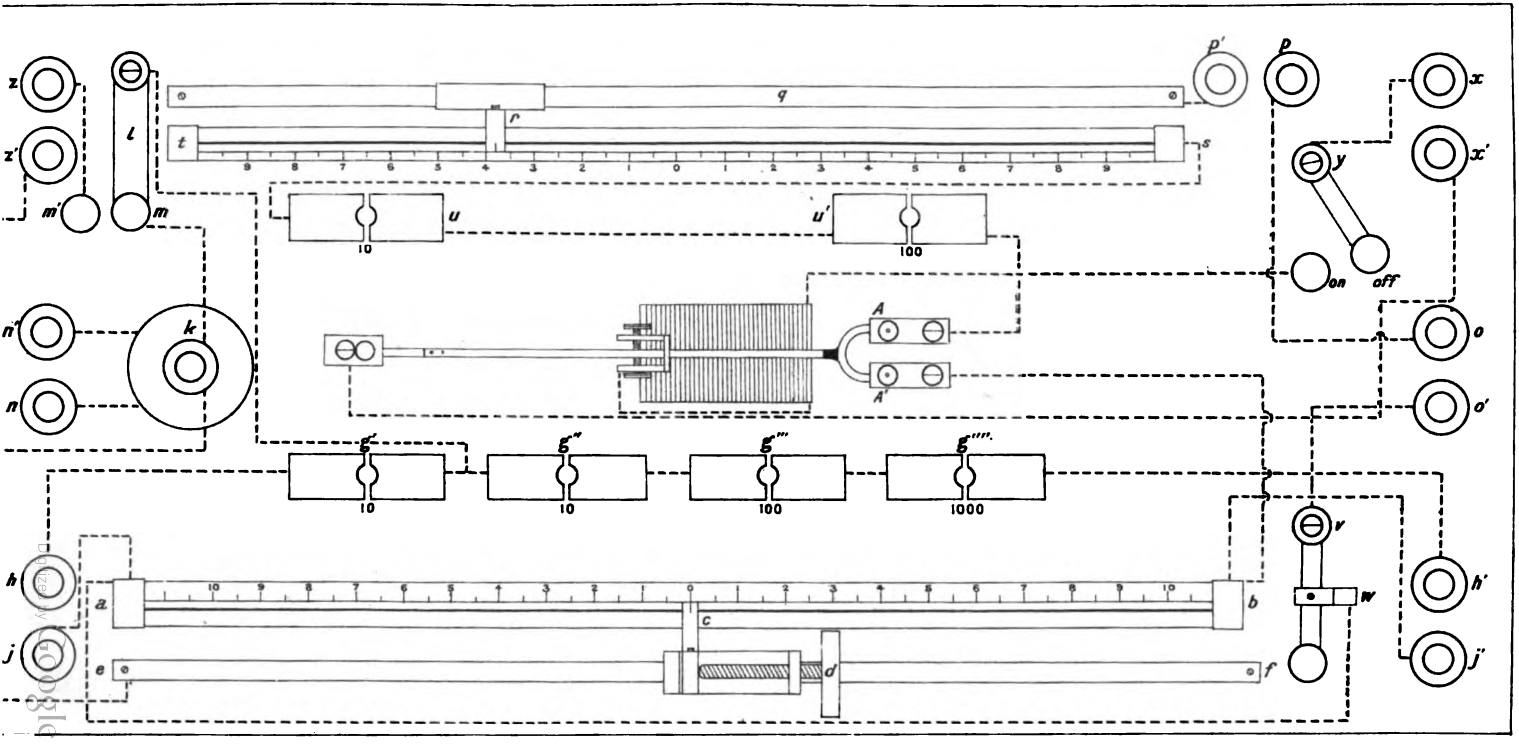

PLAN OF BRIDGE SHOWING CONNECTIONS.

J.T. MURRAY

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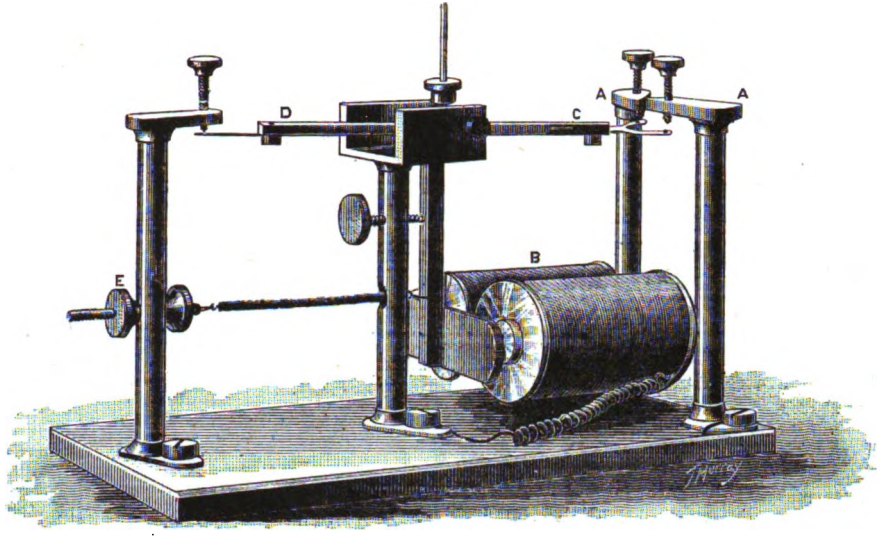

DETAILS OF RELAY.

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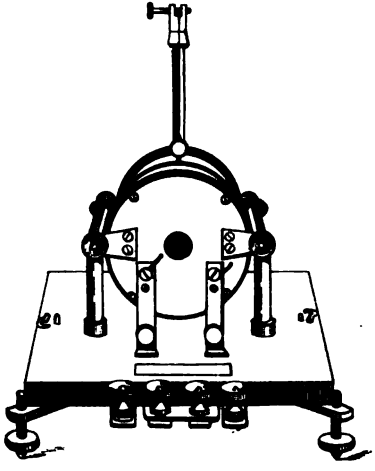

Fig 1.

GALVANOMETER WITH COILS FIXED.

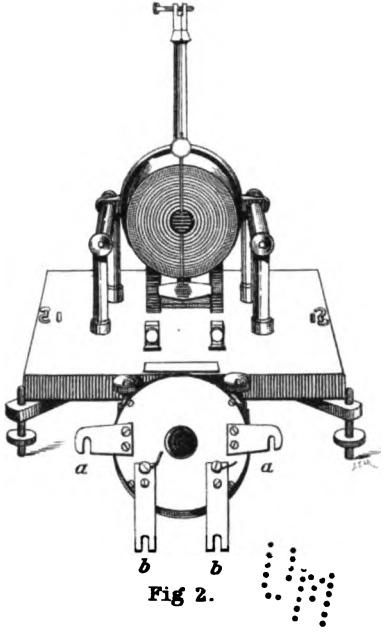

Fig 2.

GALVANOMETER WITH FRONT COIL REMOVED.

J.T. MURRAY

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On the Employment of Gas for Heating and Lighting Purposes.

By W. Ivison Macadam, F.R.S.E., F.I.C., F.C.S., &c., Professor of Chemistry, New Veterinary College, Edinburgh, Consulting Analytical Chemist.*

Ordinary town gas as manufactured from coal or oil contains as its principal ingredients,—hydrogen, marsh-gas, carbon monoxide, heavy hydrocarbons, nitrogen, carbonic dioxide, &c.

Of these substances the heavy hydrocarbons are illuminating, whilst hydrogen, marsh-gas, and carbon monoxide burn with non-luminous flames. Nitrogen and carbonic dioxide are non-combustible gases.

The relative value for illuminating purposes is estimated in standard sperm candles, each consuming 120 grains of sperm per hour; whilst the heating value is stated in heat units, each of which can raise 1 kilogramme of water one degree in temperature. The heating values of the combustible bodies are :—

	1 grm. = thermal units.
Hydrogen, ...	33,808 (Andrews).
Marsh-gas, ...	13,108 „
Carbon monoxide, ...	2,431 „
Heavy hydrocarbons, olefiant gas, . .	11,942 „

For heating purposes, therefore, the non-illuminating gases are most valuable, and the larger the percentages of these bodies the better the result.

The illuminating values of the combustible gases are :—

Hydrogen, ...	non-illuminating.
Marsh-gas, ...	„
Carbon monoxide, ...	„
† Olefiant gas, ...	.5 cubic feet = 68·5 candles = 8220 grains of sperm or 1 cubic feet = 1644 grains sperm.

So far as illumination is concerned, the hydrogen, marsh-

* Read before the Society, 9th January 1893.

† Frankland, *Jour. Chem. Soc.*, vol. xlv. p. 35.

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gas, and carbon monoxide act as dilutents, as also do the nitrogen and carbon dioxide, but the oxygen increases the luminosity to a certain extent.

Frankland has conducted a series of experiments to determine how far these gases influence the luminosity, and the results will be found in the *Journal of the Chemical Society* (vol. xlv., &c.). The tests show that whilst there is a gradual and decided loss in luminosity as the percentage of non-luminous gas is increased, that the loss is irregular. The principal results show :—

Per cent.		5 cubic feet =
Ethylene (97·52)	. . . .	68·5 standard sperm candles.
„ + 22·45	Hydrogen, . .	54·58 „ „
„ + 31·61	„ . .	49·37 „ „
„ + 64·53	„ . .	30·85 „ „
„ + 73·92	„ . .	22·84 „ „
„ + 86·63	„ . .	6·73 „ „
„ + 90·00	„ . .	non-luminous.
„ + 18·35	Carbon monoxide, .	55·27 standard sperm candles.
„ + 32·25	„ „ .	47·73 „ „
„ + 53·70	„ „ .	33·09 „ „
„ + 62·06	„ „ .	26·52 „ „
„ + 71·27	„ „ .	13·36 „ „
„ + 76·11	„ „ .	6·56 „ „
„ + 80·00	„ „ .	non-luminous.
„ + 14·33	Marsh-gas, . .	57·91 standard sperm candles.
„ + 30·91	„ . .	47·88 „ „
„ + 42·26	„ . .	40·42 „ „
„ + 64·10	„ . .	33·17 „ „
„ + 87·10	„ . .	19·35 „ „
„ + 92·13	„ . .	17·59 „ „

Marsh-gas, although yielding a non-luminous flame, when burned in the ordinary way may be, by heating, compelled to yield a luminous flame. These combustible dilutents improve the luminosity of the ethylene present, for if we calculate the candle value of the ethylene alone, we find that whilst 5 cubic feet of 97 per cent. ethylene is equal to 68·5 standard candles, that 5 cubic feet of the ethylene in a mixture with 92 per cent. marsh-gas gives a light equal to 175 candles for the ethylene consumed.

In the non-combustible gases oxygen stands alone in increasing the light value.

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	Per cent.			
Ethylene	+ 17·43	Oxygen,	70·93	standard candles.
„	+ 19·33	„	72·52	„ „
„	+ 24·49	„	74·19	„ „
„	+ 31·50	„	71·17	„ „
„	+ 6·32	Carbonic dioxide,	55·52	„ „
„	+ 10·97	„ „	49·98	„ „
„	+ 29·25	„ „	33·23	„ „
„	+ 47·06	„ „	14·74	„ „
„	+ 54·39	„ „	7·49	„ „
„	+ 15·31	Nitrogen,	51·96	„ „
„	+ 28·88	„	39·58	„ „
„	+ 52·92	„	20·81	„ „
„	+ 63·76	„	11·82	„ „
„	+ 71·19	„	7·20	„ „
„	+ 20·32	Air,	54·45	„ „
„	+ 44·08	„	37·16	„ „
„	+ 66·09	„	16·22	„ „
„	+ 77·69	„	0·61	„ „

Aqueous vapour also has a marked influence on the illuminating value of ethylene.

Frankland thus summarises his most important investigations :—

The principal results arrived at by these experiments may be summed up as follows—

1. Mixtures of ethylene with the combustible dilutents carbonic anhydride, nitrogen, aqueous vapour, and atmospheric air possess a lower illuminating power than pure ethylene.

2. In all mixtures of ethylene with either carbonic anhydride, nitrogen, or aqueous vapour, the intrinsic luminosity of the ethylene is reduced.

3. In mixtures of ethylene with atmospheric air, the intrinsic luminosity of the ethylene remains unimpaired until the air forms about 50 per cent. of the mixture.

4. Mixtures of ethylene with oxygen in insufficient quantity to form an explosive mixture possess a greater illuminating power than pure ethylene, the intrinsic luminosity of the ethylene is greatly increased.

5. The disilluminating effects of carbonic anhydride, nitrogen, and water vapour are partly due to "dilution" and partly to "refrigeration," or the cooling occasioned by the introduction of inert gas into the flame; this refrigeration is

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proportional to the specific heats of the gases, but in the case of carbonic anhydride and aqueous vapour, it is also augmented by the absorption of heat which takes place in the dissociation of the aqueous vapour, and in the reduction of the carbonic anhydride to carbonic oxide.

6. Of the four dilutents—carbonic anhydride, nitrogen, aqueous vapour, and atmospheric air—carbonic anhydride is the most and atmospheric air the least prejudicial to the illuminating power.

Nitrogen and atmospheric air, however, become more equalised in their effect as the proportion in which they are present increases; complete disillumination of the ethylene being effected by the same proportion of each.

The effect of loss of illuminating power due to refrigeration is well known, and accounts for the lower illuminating quality of gas during severe weather.

The fact that oxygen improves the luminosity of the gas is now to some extent made use of in several gas-works. It is found that in the oxide of iron purification process the purifiers may be continued much longer in use, provided some oxygen is introduced into the gas as it enters the purifier. It is further claimed for this process that it is much less costly, and that the plant is cheaper and the room required much less.

W. A. Valon (*Gas World*, 1889, 715–719) states that placing the purification of 1,000,000 cubic feet of coal-gas at £3, 15s., the same work could be done with oxygen for £1, 15s. (cost of oxygen not included), and that charging cost of oxygen, interest on plant, &c., there is still a sum of 5s. in favour of the oxygen. If to this sum the interest (£3, 15s.) on capital due to saving one-half the space required for plant and the average cost of 1½ candle-power (at 1d. per candle, £6, 5s. per million), the saving per million cubic feet is £10, 5s., whilst if the interest on capital saved is not accounted for there is a sum of £6, 10s. still in favour of the oxygen process.

On September 1892 the

Edinburgh Works made		57,627,000	cubic feet.
Leith	„	„ 28,358,000	„
		85,985,000	„

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or practically 86 million, which at 5s. per million would be £21, 10s., or if the value of the extra illuminating power be considered, £559; whilst if the saving of capital for diminished space be considered, the results, according to the above estimates, would be £881, 10s.

The heat at which the coal is distilled very materially alters the composition of the gaseous product, whilst under low gas-making heats the liquid product is largely composed of members of the ethylene series. As the temperature is raised, that body is itself broken up, producing acetylenes and paraffins, at the same time liberating much hydrogen. The luminosity of the gas is thereby impaired. The regulation of the heat of the retorts is therefore most important, for should the temperature be too low, the ethylenes produced will be higher members of the series and condensable; whilst if the heats are too high, marsh-gas, hydrogen, and other non-illuminating gases will be formed.

Lewis T. Wright (*Jour. Chem. Soc.*, xlv. 99) gives analyses and results on this subject which show that when the heat is increased the volume of gas is also greatly increased, and that although there is a decided loss in candle-power, yet that the total candle-power from the ton of coal is increased. The figures are:—

	Gas per Ton of Coal.	Illuminating Power.	Candles per Ton of Coal.
1	8,250 cubic feet.	20·5 candles.	33,950
2	9,693 „	17·8 „	34,510
3	10,821 „	16·75 „	36,140
4	12,006 „	15·6 „	37,460

The composition of the gas is also given, and is:—

	1	2	4
H	38·09	43·77	48·02
CO	8·72	12·50	13·96
CH_4	42·72	34·50	30·70
$CnHn_2$	7·55	5·83	4·51
N	2·92	3·40	2·81

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In 1870 Dr Stevenson Macadam communicated a paper on the distillation of gas from coal to this Society,* in which he dealt with the results obtained by long and short time charges. In the investigation he endeavoured to obtain the greatest illuminating value from the coals. He treated several well-known coals to longer or shorter contact with the heated surfaces of the retort, and obtained results which showed that whilst there was a loss of about 1600 cubic feet of gas by the shorter contact, that the luminosity was increased nearly 4 candles, whilst a loss of total illuminating power was observable = $\frac{1}{30}$th of the total light.

During February last year I was instructed by the Merchants' Association of Edinburgh to make tests of the gases as supplied to the City, from the Edinburgh and Leith Works, and the results obtained were as follows:—

Edinburgh gas 27·08 standard candles.

Heavy hydrocarbon, ...	8·21 per cent.
Carbonic acid, ...	0·14 „

Leith gas 26·31 standard candles.

Heavy hydrocarbon, ...	8·16 per cent.
Carbonic acid, ...	0·18 „

By instructions received from the *Scotsman*, I tested the gas from the Edinburgh Works on the 4th, 5th, and 6th of this month, and found:—

4th January, ...	24·14 candles.
5th „	25·42 „
6th „	25·84 „

The gas supplied to the city is thus of very much higher quality than that supplied to most cities, and yet we find much grumbling as to the quality. I believe faulty fittings are much to blame, but I do not relieve the commissioners from all fault, for I consider that were they, like the Water Commissioners, required to supply the houses at so much per pound rental, they would long ere this have instructed the users in the proper methods of burning the gas. Dirty and

* *Trans. Roy. Soc. Arts*, 1870.

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insufficient pipes doubtless lend their quota to the grumbling, but the main factors are undoubtedly—(1) Pressure; (2) Burners.

I am aware that at the works much is done to regulate the pressure and keep it as even night and day as possible, but I must say I think this department should receive still more attention. I feel sure that if the Commissioners drew the attention of their two most able managers to this point, that they would easily suggest means to overcome one of the greatest sources of grumbling. The Water Commissioners see that no house has too great a pressure laid on to it, why not the Gas Commissioners? Of course, I acknowledge that all cannot be done at the works, or even at the house inlets, but much can be done.

It is also most possible that the gas managers find some very considerable trouble with the mains, which in many cases were laid down years ago and were never intended to carry the enormous quantity of gas now being pressed through them. To press a gas through a pipe is practically converting the main into a condenser, for it is well known that there is no more effective way of removing illuminating bodies from a gas than by subjecting it to "rub" against the side of a pipe. The mains should be large, so as to induce a comparatively slow speed of flow. The pressure necessary to force gas through a small pipe is great, and Edinburgh stands in the published statistics the highest of all Scotch gas-works.

The burners in use rarely, if ever, give the full illuminating power of the gas. Much work to prove this point has been done by the late Dr William Wallace of Glasgow, by a committee of the British Association, and by Dr Stevenson Macadam. These experiments were made some considerable time ago, and the burners tested did not include the newer forms. The rate at which the gas issues from the tip of a burner should be as low as possible, and to accomplish this end various means have been patented. Amongst these may be mentioned small screens of cloth, perforated discs, double burners, &c. These devices are not peculiar to one maker, but I propose to illustrate them by Bray's

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ordinary burner, Bray's special burner, and Bray's adjustable burner.

Under varying pressures, the following results were obtained:—

Pressure.	Consumption, Cubic Feet.	Candle-Power Obtained.	Candle-Power for each 5 Cubic Feet of Gas Burned.
No. 8 Bray Burner.			
15/10	7·8	35	22·69
10/10	6·5	30	23·07
5/10	5·0	25	25·00
No. 8 Bray "Special" Burner.			
15/10	5·2	29	28·03
10/10	4·3	24·5	28·37
5/10	3·1	18·25	29·42
No. $\frac{8}{8}$ Bray "Adjustable" Burner.			
15/10	5·35	41	38·21
10/10	4·6	34	36·95
5/10	3·4	25	36·76

These results were all obtained with the ordinary Edinburgh gas, and the tests were made on the same day, the gas not materially altering during the period of testing. The tests show that the double burner of the adjustable gives much the best results. It is curious to note that this double-burner system is by no means new, as I have in my possession a double "batswing" burner as manufactured by Messrs Milne & Son of Edinburgh some fifty years ago. The lower burner has a much finer slit than the upper burner. The results of my tests with this burner are given below, and although not so favourable as those of the newer Bray "adjustable," yet are in marked advance of the other varieties

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Milne's Old Double "Batswing" Burner.			
Pressure.	Cubic Feet Consumed.	Candle-Power Obtained.	Candle-Power for each 5 Cubic Feet Consumed.
15/10	6·8	48	35·29
10/10	5·6	41	36·60
5/10	4·0	29·5	36·87

Messrs Milne also quite recently manufactured an iron burner, consisting of two union jets screwed together.

The great loss of light brought about by the use of small-sized burners is still requiring attention, as will be shown by the tests given below made with "adjustable" burners of various sizes and at 15/10 pressure.

No. 3/0 . . .	19·2	Candle-power from each 5 cubic feet of gas consumed in the various burners.
No. 4/1 . . .	25·66	
No. 5/2 . . .	26·14	
No. 6/3 . . .	27·42	
No. 7/4 . . .	34·00	
No. 8/5 . . .	38·21	

I have tested a device which is evidently intended to check the pressure at the point of ignition. It consists of a small disc of metal attached to a lever, which is allowed to fall against the upright flame.

	Pressure.	Cubic Feet Consumed.	Candle-Power Obtained.	Candle-Power per 5 Cubic Feet.
No. 8 Bray burner *without* deflector,	15/10	7·8	35	22·69
	10/10	6·5	30	23·07
	5/10	5·0	25	25·00
No. 8 Bray burner *with* deflector, .	15/10	8·8	60½	34·37
	10/10	6·8	42½	31·25
	5/10	5·0	28	28·00

The deflector very greatly increases the luminous area, but the flame is somewhat unsteady.

A rather unwieldy-looking piece of apparatus consists of two No. 8 Bray burners, the flames of which may be allowed

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to impinge against one another. This St Noleton Patent Duplex gave me at 15/10 pressure :—

	Cubic Feet Consumed.	Candle-Power Obtained.	Candle-Power for each 5 Cubic Feet Consumed.
One burner, . .	3·5	7·8	11·14
Two burners, . .	6·3	34·0	26·98

In this case also, however, pressure had much effect, for both burners at 10/10 pressure gave a light equal to 28 candle-power, and at 5/10 pressures 35·29 candle-power for each 5 cubic feet consumed.

Pressure varies very greatly at the various landings in the same house, and the only way to ensure a constant pressure at the point of ignition is by the use of governor burners. One of the best known of these burners is that invented by Mr D. Bruce Peebles, a member of this Society. The burners I used were regulated for pressures of 10/10 and upwards. With the No. 6 burning 4 cubic feet per hour I obtained at—

10/10 pressure . .	28·29	Candle-power obtained for each 5 cubic feet burned.
15/10 „ . .	28·21	
5/10 „ . .	28·57	

I have made a long series of experiments with various burners working under varying pressures and with different qualities of gas, but these are too lengthy to be quoted in this communication, and will form a separate paper by themselves.

I cannot, however, conclude without shortly referring to the manufacture of gas from oil. This subject I have previously discussed before this Society. The Peebles process of Messrs Young & Bell is now a working reality, for in January of this year it manufactured 223,400 cubic feet of oil-gas, which was afterwards mixed with 1,247,600 cubic feet of splint coal-gas, yielding a mixture with an illuminating value of 30·51 candles per 5 cubic feet burned. In November 1892, there was made at Peebles a total of 1,355,600 cubic feet, of which 231,700 cubic

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feet was from oil, and in December 1892 a total of 1,293,300 cubic feet, of which 268,100 was from oil. These figures show how valuable oil is for the manufacture of gas, and the Peebles process has undoubtedly settled any doubts which gas managers may have entertained as to the feasibility of the process. The cost is also much lower than when gas is made from coal, for the Peebles gas only costs per 1000 feet delivered to the holder, for materials, wages, &c., and after deductions for value of residuals, about 1s. 4d.

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On Water and Water-works: An Address by the President, ALEXANDER LESLIE, M. Inst. C.E., F.R.S.E., F.G.S., *delivered at the Annual General Meeting of the Society held on* 13*th November* 1893.

GENTLEMEN,—I wish to refer for a few moments to the subject upon which I had the honour of addressing you on a similar occasion last year, and probably you will recollect that I then dealt with the subject of several of the largest water-supplies in this country.

To show you what progress has since then been made in these works, I may mention that, in the case of Glasgow, the puddle trench of the large service reservoir at Craigmaddie, which was excavated to its full depth 12 months ago, has now been filled with puddle. It was not until a depth of fully 200 feet had been reached, that a reliable water-tight foundation was obtained, and it is satisfactory now to know that all the difficulties connected with this undertaking have been overcome, and that the remaining works in connection therewith are proceeding rapidly. With regard to the aqueducts and tunnels which are now being constructed between Loch Katrine and Glasgow, several of them have been completed, and, although there are some which have not yet even been commenced, I am able to inform you that, by the works which have up to this time been executed, Glasgow has been put in possession of an addition to its water-supply of about 5 million gallons per day.

By an ingenious arrangement, the carrying power of the existing aqueduct has been augmented, and an

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improvement on the existing supply obtained, which will keep Glasgow for many years from the point of actual want of water.

With regard to Birmingham, the large scheme which we spoke of last year has actually been set on foot. One can judge of the immensity of it when it is known that, previous to entertaining the idea of commencing the water-works themselves, it is actually necessary to construct for that special purpose a railway to traverse the whole course of these works. The contracts for this railway have been let, and the work is now in progress.

As to the Manchester water-works, there is not much new to say about them, except that, within a few months from now, the whole structural work in connection with the Thirlmere Reservoir will be completed. The only subject for regret is that, although the water is there, and was available for use for a considerable time before now, and at a time when the Manchester district was actually on half supply, on account of some unfortunate clause in the Act of Parliament which authorised the construction of these works, it was not technically legal to send water to Manchester until some minor and altogether insignificant auxilliary works had been completed. This is one of these unfortunate instances which are by no means uncommon, when, in consequence of some ill-advised or meaningless clause in an Act of Parliament, inserted probably in all good faith by the agent of some landowner or landowners, stipulations are agreed to and become binding which, while they confer no real benefit on the parties proposing them, have a most prejudicial and irritating effect upon the promoters of the scheme. Instances of this kind of

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persecution have frequently come under my own observation.

It seems that, in this case, it was arranged that no water should be taken to Manchester, dying for want as it was, until some road, the construction of which could materially benefit no one, was completed, and thus the matter stands.

With the example of Manchester before us, and also that of places much nearer home, I think a fair warning has been given to those who have the charge of the engineering and pioneering of measures of this sort through Parliament, to take great care that they are not coerced, by simple overbearing attempts on the part of opponents, to submit quietly to have any legitimate scheme saddled with obligations, the execution of which can only annoy the promoters and not in any way benefit the authors of them.

With regard to the works for the supply of Liverpool, there is no doubt that all connected with the concern are delighted to have the benefits which this new supply affords them. From an engineering point of view, the only drawback in the whole affair seems to be that one of the tunnels, which conveys the water through a mountain, has to be lined to prevent further disintegration of the natural rock roof, a thing which no one can object to, though involving trouble and expense to some extent.

The result of the introduction of this grand addition to the supply to Liverpool is, as might be expected, that the supply per head per day has somewhat increased, and here the question is again suggested, whether it is better to spend money upon economising water by the prevention of its use or abuse, or to expend it upon introducing additional supplies. In

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the case of Liverpool, the money has now been spent for the latter purpose, and no one grudges the result, and besides benefiting the actual population of Liverpool itself, numerous outlying districts have been enabled to secure through it a plentiful supply of water for all their needs.

I shall now say a few words with reference to the water-supply of London, the largest city in the world. Authentic accounts exist of the numerous schemes which were from time to time adopted to keep pace with the increasing wants of the inhabitants; the first of these which is mentioned dating back to the time of William the Conqueror, when the river of Wells or Wallbrook is mentioned in the Charter of the College of Saint Martin le Grand.

Prior to the construction of the water-works at London Bridge and the New River Company's works, the inhabitants obtained their principal supply, either from the Thames by lifting it out in pitchers, or from some springs which rose on high ground to the north or west of the city, and it was distributed by means of leaden pipes and delivered from conduits or fountains erected at various points throughout the district of supply.

Information regarding these relics of antiquity is to be obtained from the writings of the celebrated antiquarian John Stow, who lived in the reign of Queen Elizabeth. It is interesting to observe what a large number of names are to be found throughout the Metropolis, having as their origin something connected with water-works—Wallbrook, Holywell, Clementswell, Clerkenwell, Horspool, Holburn, and very many others which are evidently called after water-works existing at one time in their vicinity.

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The first leaden cistern which was constructed in London, was commenced in the year 1235, and the whole work in connection with this scheme was, however, not completed until 50 years later. We are informed that the lead pipes, which were then employed for distributing the water, were not buried in the earth, as is now the usual custom, but were enclosed in culverts of brickwork which workmen could enter for the purpose of effecting the necessary repairs. This plan, it may be observed, has of recent years been occasionally adopted, but it has the disadvantage of tending to produce dangerous explosions in consequence of the leakage which almost always is found to take place from the adjacent gas mains.

The London water-works were added too from time to time, but it was not until 1582 that any improvement of importance took place. At this time a Dutchman, named Peter Morris, obtained authority from the Lord Mayor to erect a pumping engine at London Bridge, which was driven by the current of water flowing through one of the archways. This appliance turned out a complete success, giving great satisfaction, and it was not until about the year 1820 that this source of supply was finally abandoned, the polluted condition of the water of the Thames rendering this step inevitable.

Everybody has probably heard of Sir Hugh Middleton, by whom the works for introducing the water from the New River into London were designed and carried out. The New River Company was incorporated by Charter in the reign of James I., bearing date 21st June 1619, and the works are still the property of the New River Company which supplies

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a large proportion of the total amount consumed in London.

The following table gives the names of the eight different London Water Companies, with the population supplied, and the amount provided per head by each of them :—

Name of Company.	Supply per day.	Population.	Supply per head per day.
	Gallons.		Gallons.
New River, ...	32,640,976	1,159,260	28·16
East London, ...	39,704,601	1,158,500	34·27
Chelsea, ...	9,557,388	287,362	33·25
West Middlesex, . . .	15,419,907	577,235	26·71
Grand Junction, . . .	16,701,734	350,000	47·72
Lambeth, ...	20,234,560	655,921	30·85
Southwark and Vauxhall, .	24,373,348	841,989	28·94
Kent, ...	12,530,871	460,524	27·21
	171,163,385	5,490,791	31·19

It will be observed that the Grand Junction Company provides the extravagant amount of 47·72 gallons per head, which, considering that the water is all provided by pumping, is rather astonishing; but, from the statement of the Company's engineer, it seems that it has been found cheaper to pump up this additional quantity than to spend money in attempting to suppress waste. This principle will require to be departed from when the total available supply in the water-shed, from which London at present derives its water, comes to be more nearly utilized.

The question of London water-supply has, on more than one occasion, formed the subject of a Royal Commission of Enquiry, and the question of taking the works out of the hands of the Companies and placing them under the jurisdiction of the London

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County Council was under consideration a few years ago.

After a long and careful investigation into the circumstances of the Companies, it was decided, in the meantime at least, to let matters remain as they were. During the Royal Commissioners' Enquiry of about 25 years ago, it was urged by several parties that the water provided by the Companies from the river Thames was injurious to health, and should be discarded in favour of gravitation supplies, which were suggested from prodigious distances—from the English Lakes and the hills in North Wales. Nothing, however, came of this, and the matter was allowed to rest for a time.

A Royal Commission has just recently concluded its labours on an enquiry of a similar nature, and its chief object was to determine, if possible, whether the water, which was being supplied to London from the water-sheds adjacent, was sufficiently good and sufficiently abundant to last for some considerable time. It may appear strange to those who have not considered the subject, and perhaps more strange to those who have, that it should be possible for London to draw its main supplies of water from the Thames, on the banks of which are situated so many large and important centres of civilisation—Oxford, Windsor, and many other towns and villages, which, until quite recently, have been in the habit of letting their sewage right into the stream. Of recent years, however, methods of purification have certainly been adopted, some of which are efficient, others probably less so.

The result of the deliberation of this Royal Commission is, that they have come to the conclusion

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that the water which is being delivered is perfectly wholesome, provided that proper care is taken to prevent as much as possible the admission of sewage into the streams from which the supply is pumped, and that it is properly filtered before being distributed for use, and also that there is within the existing water-sheds sufficient water still available which would bring up the total supply to 420 million gallons per day, or 35 gallons per head, to a population of 12 millions, a figure which it is not expected will be reached until after the expiry of nearly half a century, so that, so far as now can be seen, the only probable alterations on the London water-works will consist of developments and extensions of the existing works on much the same lines as those on which they are being conducted at the present time.

And now for a few words in connection with the special question of water itself.

Many writers on this subject seem to deem it absolutely necessary to preface their remarks with a reference to the doings of the Egyptians, Phœnicians, and others of almost prehistoric times, probably including some allusion to the ancient Romans, who, we are often told, were in the habit of using not less than 300 gallons of water per head per day, and finishing up by making invidious comparisons with the modern users of water, very much to the disadvantage of the latter, who are generally held up to execration if they venture to use or consume more than a tenth part of what our Roman friends were in the habit of doing; but the Romans lived in other times than ours, in fact they flourished in "the grand old days of yore" when "might was right" and "man was man," and when he thought for himself instead of waiting

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for inspiration on this sort of question to be served up along with his breakfast; before the days of cheap journalism and Deacon meters, both of which may be good enough in their proper place, but when taken together are not necessarily always an unmixed blessing.

Others, in treating of this subject, go still further back, even to the first chapter of Genesis, and start with a long story about Oxygen, and Hydrogen, and so forth. We have got past these preliminaries, and I wish on this present occasion to look at some of the more important features of this subject.

We shall first consider the chemical aspect of the case, viz., the examination of waters by analyses. It is an acknowledged fact that, so far as the examination of mineral subjects is concerned, analytical chemistry is in a very advanced stage; but, with regard to organic chemistry, it is almost universally admitted that this is not so, nor can this be wondered at, when the great number of bodies which have to be considered is taken into account, many of which have for their chemical constituents not more than three or four elements, with the proportions of these elements nearly the same. Other complexities arise when the substance itself is liable to rapid decomposition, and a degree of complexity is thus introduced into the question of analyses, which makes it almost impossible to solve the question satisfactorily in the present state of chemical science. The water analyst has got to encounter many of the difficulties above alluded to.

It was, and properly enough, always the practice of Local Authorities, and those similarly entrusted with the administration of water supplies, to submit for the consideration of some analytical chemist of known

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ability, samples of the water which some engineer might have suggested as a proper supply for the community under their charge.

There is a wide difference between the methods employed then and now, and it is interesting and instructive to note wherein the difference chiefly consists. Formerly the analyses divided itself into two parts, viz., the searching for organic and inorganic impurities.

The determination of the latter is a very simple matter, and, unless they exist in enormous excess, they are really practically harmless. Possibly metallic poison might exist, but in this country the chance of that is very remote. It might also be that lime would be found to exist in the water, either as carbonate or sulphate, the existence of either or both being beneficial or the reverse, according to the use to which the water was to be put. For brewers nothing could be better than a large amount of sulphate of lime, while the ordinary householder would much prefer that carbonate of lime was the hardening cause, as, previous to using the water for cooking or washing purposes, it would disappear in the process of boiling along with the carbonic acid by which it was held in solution.

At one time I certainly think that the organic part of the question was far too little thought of.

The original method of estimating the organic matter in water, intended to be used for drinking, was by incinerating the residue left on the evaporation of the sample, and it certainly was a simple enough one. After being heated to redness in a platinum dish, the residue was weighed, and after a little manipulation with some chemical reagents, the residue, after again being dried, was weighed, and the difference before

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and after incineration, amounting possibly to a few grains per gallon, was assumed to represent the amount of organic matter present in the water.

The whole conclusion drawn from this investigation as to the organic constituents of the water was, that if the dried residue blackened and gave off an offensive smell, especially one of burnt hair, the organic matter consisted of animal material, possibly excreta of recent origin; whereas, if the blackening produced by incineration happened to disappear on contact with the air, it was assumed that the organic substance which was being investigated was likely of vegetable origin, and, therefore, possibly less hurtful to the parties partaking of it.

Some years ago another method, a great improvement upon the preceding, was introduced for the purpose of estimating, with something like certainty, the amount of organic matter existing in waters subjected for analyses, called the albuminoid ammonia method.

This expression is by no means free from objection, as it is apt to convey an erroneous idea to the minds of most people who are not instructed in the subject.

By this method an estimate of the organic impurities in water is obtained by determining the amount of ammonia produced by their decomposition when treated in a certain manner. It is out of place here to go into the details of this process, but it has undoubtedly the merit of great simplicity. No previous evaporation is necessary, and this alone serves to save time, which is often of importance in investigations of this kind.

With all the information obtainable or deducible from the operations above described, it is undoubtedly a fact that people may be very much misled by the

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chemical results obtained, as I recollect perfectly well being astonished at one time, nearly twenty-five years ago, when the late Mr Hawksley said "I cannot conceive the object of fussing about the presence of what is called albuminoid ammonia, when the insertion of a piece of cheese of the size of a pin-head in a gallon of water would give them enough to frighten the consumers out of their lives, if they believed that the chemist's conclusions were anything approaching to correct." It therefore must be obvious that, before either accepting a water or condemning it as unfit for use, something more is required than the chemical report of a chemist, confined most probably to his laboratory. There is no doubt, therefore, that chemists should, as far as possible, have the opportunity of selecting their own samples, as, by the stupidity or carelessness of ignorant subordinates, water of the finest quality may be often reduced into a condition which, so far as chemical analyses is concerned, would make it seem to be utterly unfit to use, which, had the matter been properly gone about, and the samples taken by the chemist himself in his own properly accredited utensils, would have passed the ordeal of examination with a much more creditable result.

There are other things, however, besides the mere taking of the samples, which ought to be considered. To my mind it is utterly absurd to pin one's faith to a single analysis, even of the semi-crude kind to which I have alluded.

I know of streams in dozens in this country which are at times capable of sending down water as foul and objectionable as possible—the colour of sherry being nothing to them—on account of the peaty and other extraneous admixtures, which same streams have been

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sampled by myself in certain favourable conditions, such as during long droughts or during hard frost, and have been as pure as crystal, and as free from pollution almost as distilled water; therefore, I say that for a community, as is so often the case, to blindly follow the verdict of a chemist, himself debarred from proper knowledge of the circumstances of the case, is simply absurd.

What ought to be done is for the chemist and the engineer to go together and examine the area from which the water flows. The one may point out objections which the other may suggest a means of remedying, and it is only by a proper co-operation of this kind that any successful and satisfactory report can be made available for the guidance of those in whose hands has been placed the most important duty of the providing of water supplies for the community.

To go even further than this, the late Mr Hawksley used to say it required more than even engineers and chemists, because when their function was done, the physician ought to step in, because it was his department to state whether certain facts connected with water were to be considered in its favour or the reverse; and Mr Hawksley was by no means far wrong in his opinion.

Comparatively recently the examination of waters has been conducted on an entirely different principle, and, by the aid of the microscope in the hands of biologists, wonderful results have been obtained.

Much valuable information on this subject has recently been collected, and is to be found in the Report of the Royal Commission on London Water Supply, previously alluded to, and also in a paper by Dr Percy Frankland, read before the Institution

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of Civil Engineers, London, while a still more elaborate paper has lately been published by the celebrated Dr Koch, who seems to be the pioneer in this branch of biological science.

It has been recently discovered that the matter, the existence of which in drinking-water gives it the power to spread infectious diseases, consisted of living vegetable organisms, known as microbes or bacteria. These microbes are to be found in the air we breathe, and the water we drink, and they swarm within our own bodies to such an extent that it is said that six different species are invariably present in the human mouth, while many other species are less frequently to be found there. Fortunately, the great majority of these microbes are perfectly harmless, while many of them serve a useful purpose in the breaking up of dead animal and vegetable matter, thereby reducing it into inorganic substances, and, consequently, the water inhabited by them is purified, and many species act as preventives of infectious disease.

A less desirable class of these microbes named "pathogenic" are given off from the bodies of animals already suffering from the special disease to which they respectively give rise, and should they find their way into the system of other animals or human beings capable of suffering from such disease, they communicate to them the infection.

It is held by some authorities that water that has been liable to contamination by the sewage of any number of people within its water-shed, should be forever considered totally unfit for drinking purposes, as when once polluted it remains so for an indefinitely long period, and that no subsequent treatment by

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filtration, or otherwise, can be trusted to free it from the pathogenic organisms that have once got into it. It is, on the other hand, urged that there are numerous conditions which lead to the destruction or elimination of the pathogenic bacteria during the flow down the stream, and also during the process of filtration, and, in the case of the river Thames, none have ever been detected in it, in spite of frequent search for them.

One reason for believing that water is not necessarily permanently injured by the introduction of sewage is, that it has been decided that typhoid dejecta do not retain their infectiveness for an unlimited period. In fact, according to several bacteriologists, such dejecta begin to lose their virulence after a very few days, and the longest period for which the typhoid bacillus has as yet been found to retain its vitality when in fæcal matter, does not exceed fifteen days, so that it is only from typhoid dejecta of very recent deposit that danger is to be apprehended.

Another fact in connection with the power of water to act as a carrier of disease is that typhoid or enteric fever can only be communicated by means of human agency, and that the droppings of cattle, sheep, pigs, and other animals, however objectionable on other grounds, cannot be regarded as a possible source of such disease.

The disappearance of pathogenic bacteria from water, into which they may have accidentally been introduced, is accounted for by biologists by the fact that their natural habitation is the interior of the living body, and when they pass from this into the outer air or into water they find themselves in an

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unnatural medium and become weakened thereby, and thus fall an easy prey to the ordinary water bacteria with which they are surrounded and in a more healthy condition. It appears to be the generally accepted doctrine of bacteriologists that pathogenic organisms and the ordinary river bacteria to which the decomposition of organic matter is due, are antagonistic. This idea is borne out by the fact that pathogenic bacteria will live longer in distilled water, or water that has been previously sterilised and from which all other bacteria have been removed, than in ordinary river water.

It is also understood that sunlight has the effect of killing these noxious germs which naturally thrive in the dark interior of human beings, and this would indicate that the hitherto invariable practice of protecting clear water reservoirs from sunlight by vaulting or otherwise, is not necessarily the best plan. Whether or not this may be so, the result of leaving filtered water exposed to the sun's rays is, that vegetable growth of most objectionable character and quantity is sure to take place, and, leaving biology out of consideration, I would feel inclined to continue this practice.

Experiments have also demonstrated that mere settlement, such as takes place with water when stored in reservoirs, tends to get rid of bacteria of all kinds, and this is due, as is generally believed, to the entanglement by the mud in suspense of the bacteria present in the water. Clark's carbonate of lime process for softening water has been stated to remove no less than 98 per cent. of the living organisms in the water experimented on.

For long it was believed that filtration through

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sand could only separate, from the water operated on, substances such as mud or clay, which were visibly held in suspension by it, but recently those, probably, best qualified to judge, have come to the conclusion that greater changes than this can be effected by the passing of water through sand, and here again there is a difference of opinion as to the effect—some authorities maintaining that filters are most effectual when perfectly clean, others believing that the best results are obtained after the surface of the sand has become covered with an accumulation of gelatinous organisms, and that, as it is only under these conditions that bacteria can be kept back, the frequent cleansing of the filtering medium is not only unnecessary, but actually disadvantageous.

A most useful set of observations on the question of the effect of filtration on cholera microbes has recently been published by Dr Koch, and, by a long and exhaustive chain of facts and deductions, he offers us the comforting assurance, that, notwithstanding that river water may be actually swarming with these pathogenic bacteria derived unmistakably from the admission of the dejecta of cholera patients, their removal can be safely depended on by the adoption of efficient filtration. After calling attention to the recent outbreaks of cholera at Hamburg and Altona, he shows that although Altona derives its water supply from the river Elbe, which received the sewage of the cholera-stricken town of Hamburg, the number of cases of cholera in it was quite insignificant in comparison with what took place in Hamburg itself. He insists strongly that the disease is conveyed mainly, if not entirely, by water, and that the other surrounding circumstances, such as climate and soil, have little or nothing to do

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with the subject, and this is scarcely to be disputed when it is shown, that in several well-marked instances, this dire plague claimed as its victims the inhabitants of one side of a set of streets, leaving their opposite neighbours entirely free from the scourge—the reason pointed out being, that those who were smitten were supplied by unfiltered Hamburg water, while those who escaped were the fortunate users of the Altona water. This was, as he shows, the result of proper filtration, and he insists strongly on the necessity of carrying out the process of filtration with a velocity of not more than 4 inches per hour, if the separation of these pestilent organisms is to be successfully accomplished, a rate of about two-thirds of what is usually adopted here.

It is most satisfactory, therefore, to know that in this country filtration is almost invariably adopted in water supplies, and comfort may also be afforded to those who dread the result of the manuring with police refuse of fields draining into streams from which water supply is drawn, that biologists believe that the pathogenic organisms, which possibly might have at one time existed in such refuse, will, before its being applied to the ground, have all disappeared.

It would, of course, be presumptuous of me to question the accuracy of the conclusions arrived at on this question of bacteriology, which, however, may be said to be still in its comparative infancy, but I would by no means be surprised if new theories were to be started before long of widely different nature. What if it should turn out that the removal of these very organisms from drinking-water were a mistake. Not a hundred years ago, an energetic working farmer thought to improve his fields, by removing with much labour all the land stones, which seemed to him to be

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acting only as cumberers of the ground. Nature knew more about farming than he did, and a short experience of this so-called improved state of matters convinced him that he had made a great mistake, and his next step was to cart them all back again. We all know what a mistake it is to destroy the natural balance of power in nature, and what has been the result of trying to improve matters by human interference? Witness the result of the unfortunate introduction of rabbits into Australia. Are we sure that the suppression of bacteria is a safer principle to act on than the slaughtering of hawks and other birds of prey, the effect of which was generally admitted to be the inconvenient increase of other animals, which, by their aid, would have been kept in check.

With regard to the present condition of the Royal Scottish Society of Arts, I have with regret to say that the list of Fellows is not so numerous as it was a year ago. Ten names have been removed by death, and what is, I think, even more to be regretted, as not being inevitable, eleven members have resigned—the result being that, after allowing for all the new members elected during the year, the number on the roll now stands at 311, instead of 320, as I announced at the beginning of last session.*

* We find the following names in the list of deceased Fellows :—

James Andrews, C.E.,	who joined in	1863.
James Carlisle, Engineer,	,,	1862.
Thomas Dunn, Optician,	,,	1844.
Laurence Hill, C.E., Glasgow,	,,	1839.
William Johnstone, C.E., Glasgow,	,,	1850.
John Macrae, C.E., Edinburgh,	,,	1872.
D. C. Mudie, Engineer,	,,	1858.
William Sturrock,	,,	1885.
J. Bryce Scott,	,,	1893.
Robert R. Horne,	,,	1870.

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Of the ten deceased Fellows it happens that no fewer than six belonged to the same profession as myself, and with all of them I was from time to time professionally engaged—the late Mr Laurence Hill, of Glasgow, who was the author of one of the communications laid before the Society during last session, was one of the oldest members on the list, and was some years ago congratulated on the completion of his fiftieth year of membership. There are five names still on the list who have belonged to this Society for upwards of that time.

Before concluding, I have again to urge the necessity of individual members doing their best to promote the welfare of the Society by endeavouring to increase the number of its members, and also to spare no pains to contribute to the work of the session by submitting papers on subjects of interest and importance, as unless this is done and greater vitality, so to speak, is infused, the hitherto acknowledged prestige of this body cannot be expected to continue.

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APPENDIX (A).

Proceedings of the Royal Scottish Society of Arts, Session 1890–91 (being the 70th Session).

First Meeting.—The Annual General Meeting was held on the 10th of November 1890. The Right Honourable Lord Kingsburgh, President, occupied the Chair, and was supported by Mr D. M. Westland, Vice-President.

The President opened the Session by delivering an interesting Address referring to the origin and early history of many well-known inventions, including amongst others, Fire-Arms, Steam Navigation, Screw Propulsion, Railways, Gas, Telegraphy, &c., concluding with some appropriate remarks on the Forth Bridge.

On the motion of Dr Stevenson Macadam, seconded by Mr Westland, a hearty vote of thanks was accorded to the President for his Address, and it was agreed to print same in the Society's *Transactions*.

The Secretary then read the Report of the Prize Committee, and the President handed the Prizes to the several recipients.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

II. In terms of Law XV., the Society then proceeded to elect its Office-Bearers for Session 1890–91, as follows:—

President,	The Right Hon. J. H. A. Macdonald, Lord Justice Clerk of Scotland, C.B., LL.D., M.I.E.E., F.R.SS. (L. & E.)
Vice-Presidents,	Richard Kerr Miller, Consulting Engineer. Walter B. Blaikie, Printer.
Secretary,	William Allan Carter, M. Inst. C.E.
Treasurer,	Charles W. W. Thomson, C.A.
Editor of Transactions,	Stevenson Macadam, Ph.D., F.R.S.E.
Medalists,	Alexander Kirkwood & Son.
Officer and Collector,	James Stevens.

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Councillors.

THOMAS BOND SPRAGUE, M.A., F.R.S.E.
WILLIAM TAYLOR, M.D., F.R.C.P.E.
DANIEL WILLIAM KEMP, J.P.
JOHN COOPER, C.E.
WILLIAM STURROCK.
ROBERT MITCHELL.
JAMES R. CARPHIN, C.A.
FRANCIS B. IMLACH, F.R.C.S.E.
JAMES H. CUNNINGHAM, Assoc. M. Inst. C.E.
A. F. CLEMENT, Electrician.
CHARLES A. STEVENSON, B.Sc., M. Inst. C.E.
ALEXANDER LESLIE, M. Inst. C.E.

III. The following Candidates were admitted as Ordinary Fellows:—

John Cushney, Electrical Engineer, West Drayton, London.
Robert Miller, Lord Dean of Guild, Edinburgh.
William Ed. Jones, Schoolmaster, Stanley House, Bridge of Allan.
Thomas L. Saunders, Arthurlie, Barrhead.
Charles Miller Heron.
W. Scott Morton.
William Graham Yooll, Oil Refiner, Leith.

Second Meeting—24th November 1890.—Mr R. K. Miller, Vice-President, in the Chair, supported by Mr W. B. Blaikie, Vice-President.

The Secretary read a paper communicated by Professor G. Hudson Beare, University College, London, entitled "Notes on a Method of Testing Boiler Economy, and Results of such a Trial." A discussion followed the reading of the paper, in which Messrs Blaikie, Stanfield, Umpherston, Firth, the Secretary, and Chairman took part. The thanks of the Society were accorded to the Author, and it was agreed that the paper should be printed in the *Transactions*.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

II. The following Candidate was admitted as an Ordinary Fellow:—

Thomas Mackintosh, M.A., W.S.

Third Meeting—8th December 1890.—Mr R. K. Miller, Vice-President, in the Chair.

The Secretary read a paper on the Early History of the Steam-Engine and Steam Navigation, and received the thanks of the Society for same. Mr J. H. Cunningham exhibited some fine photographs of the Operation

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of Floating a Span of the Bridge over the Ohio River, Pittsburg, into position. The photographs were greatly admired, and Mr Cunningham received the thanks of the Society for submitting them.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

II. The following Candidate was admitted as an Ordinary Fellow :—

John Miller Richard, 20 Grosvenor Crescent.

Fourth Meeting—12*th January* 1891.—Mr W. B. Blaikie, Vice-President, in the Chair, supported by Mr R. K. Miller, Vice-President.

The Chairman, in opening the Meeting, alluded in feeling terms to the death of Dr Sang, the oldest member of the Society, and who had for so many years acted as its Secretary. The Secretary was instructed to write a letter conveying the sympathy of the Society to his Representatives, and such letter was ordered to be engrossed in the Minutes.

Dr Black then submitted a Communication on a Collection of Minerals, and of his visit to the Mining Exhibition at the Crystal Palace. A discussion followed, in which Messrs Miller, Procter, Mather, and Dr Macadam took part, after which the Chairman conveyed the thanks of the Society to the Author.

Dr Milne Murray then submitted his paper on an Electrical Bench for Physiological Research, illustrated by the Bench itself and numerous Diagrams. In the discussion which followed, Dr Ferguson, Mr Johnston Stephen, Mr Brown, and the Chairman all spoke of the arrangement in terms of praise, and the Author received the thanks of the Society. The paper was then remitted to a Committee of Dr Ferguson, Mr Johnston Stephen, and Dr Taylor, the latter being Convener, who should report to the Society.

Private Business.

I. The Minutes of last meeting were read and confirmed.

II. The following Candidate was admitted as an Ordinary Fellow :—

Henry Mowbray Cadell of Grange.

Fifth Meeting—26*th January* 1891.—The Right Honourable Lord Kingsburgh, President of the Society, occupied the Chair, supported by Mr R. K. Miller, Vice-President.

The first paper was submitted by M. J. W. Baird on Patent Silent Carriage-Wheels, who also exhibited a sample of the wheel in question.

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A discussion followed the reading of the paper, and the Author was thereafter thanked by the President, and the paper remitted to a Committee of Messrs Wilkins, Brebner, and Firth, the latter being Convener, who should report to the Society on the invention.

Mr W. S. Blaikie then read a paper on a Hospital Table and various Ambulance Appliances, exhibiting examples of the different arrangements. Dr Caverhill supplemented the information given by Mr Blaikie with a short account of improvements in Ambulance arrangements adapted for Cavalry Service. A discussion followed, in which several Medical men spoke to the advantages of the improvements introduced by Mr Blaikie, and the paper was then remitted to a Committee of Dr Imlach, Mr Bruce Peebles, and Dr Taylor, the latter Convener, who should report to the Society. The President conveyed the thanks of the Society to Mr Blaikie and Dr Caverhill for their communications.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

II. The Secretary then read letters which had passed between him and Miss Sang, which ran as follows:—

117 George Street,
Edinburgh, 14*th January* 1891.

Dear Miss Sang,—At the meeting of this Society held on Monday evening the 12th inst., Mr W. B. Blaikie, Vice-President of the Society, intimated from the Chair, in feeling terms to the Meeting, the loss which the Society had sustained through the death of your father, our oldest member, and I was instructed by the Fellows present to convey to you an expression of our deep regret and sympathy. The position which your father held in our Society was unique, both with regard to his long connection with it, extending over 62 years, and to the number and variety of the scientific communications he had contributed to our *Transactions*. The recollection of his brilliant abilities, and of the wonderful grasp he possessed of all matters relating to the Arts and Sciences, will long live in the memory of all of us who had the pleasure and privilege of knowing him.

Believe me, dear Miss Sang, yours sincerely,

(Signed) Wm. Allan Carter,
Secretary.

31 Mayfield Road,
Edinburgh, 19*th January* 1891.

Dear Mr Carter,—I beg you to convey to the President and Fellows of the Royal Scottish Society of Arts my own and my sisters sincere thanks for the very kind and feeling way in which they have made mention of our father, and for their expression of sympathy with us in the great loss we have sustained. In the midst of our grief these ex-

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pressions of sympathy are a great comfort, coming as they do from those who have been so long and so closely associated with him, as Fellows of a Society in which all his life long he took so deep an interest, and amongst whose members he numbered so many personal friends.

It will always be very gratifying to us to know that those high abilities which he undoubtedly possessed have been appreciated by and will be cherished in the memory of those he has left behind.

Believe me, dear Mr Carter, yours sincerely,

(Signed) ANNA W. SANG.

The Secretary was instructed to engross these letters in the Minutes.

Sixth Meeting—9th February 1891.—Mr R. K. Miller, Vice-President, occupied the Chair, and was supported by Dr Stevenson Macadam, and Mr Leslie, Councillor.

Mr W. Gray, junior, on behalf of his father, Mr William Gray, submitted a paper on the Heating and Ventilating of Public and other Buildings, illustrated with Drawings, Diagrams, and Models. A most animated discussion was raised over this paper, in which Messrs Key Glasgow, Mackenzie, Johnston Stephen, Whitelaw, MacNeil, Black, Bruce Peebles, Christie, Carter, and the Chairman took part, and the paper was thereafter remitted to a Committee, consisting of Professor Stanfield, Mr Kerr, architect, and Mr Blanc, architect, the latter being Convener, who should report to the Society.

The paper by Mr Hume, noted in the Billet, was postponed for want of time.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

II. The following Candidate was admitted as an Ordinary Fellow:—

Mr John Ayling, Printer, 2 Mansfield Place.

III. The proposal submitted by the Council in connection with the late Dr Sang's affairs was delayed for further consideration, and the Secretary was instructed to communicate with the Secretary of the Royal Society of Edinburgh, and advise with him on the proper course to follow.

Seventh Meeting—23rd February 1891.—Mr R. K. Miller, Vice-President, occupied the Chair, supported by Mr Cunningham, Councillor, and Dr Stevenson Macadam.

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The Secretary read a paper submitted by Mr Fairley, Burgh Engineer of Kettering, on the Sewage Purification Works of that town, illustrated with Drawings and Diagrams. In the discussion which followed, Dr Macadam, Dr Black, Mr Cadell, and others took part, and the Chairman thereafter desired the Secretary to convey the thanks of the Society to the Author.

Mr Hume then submitted a paper on Domestic Hot Water Apparatus, illustrated with numerous Drawings. The reading of the paper was followed by a keen discussion, in which Messrs Mackenzie, Procter, Ferguson, Macadam, Bruce Peebles, Gray, Black, Thomson, and others took part, and the thanks of the Society were then awarded to the Author. The paper was remitted to a Committee consisting of Mr Ivison Macadam, Mr Procter, and Mr P. L. Henderson, the latter being Convener, for the purpose of being reported on.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

Eighth Meeting.—The Right Honourable Lord Kingsburgh, President, occupied the Chair, and was supported by Mr Blaikie, Vice-President.

A paper was submitted by Dr R. Milne Murray upon a Sensitive Galvanometer. The paper, after being read and the instrument exhibited, was remitted to the Committee in charge of Dr Murray's former paper, viz., Dr Ferguson, Mr Johnston Stephen, and Dr Taylor, Convener.

The Secretary then read a Communication from Mr Jefferds, London entitled, "How to Reduce Railway Rates and Increase Dividends thereby." A discussion followed the reading of the paper, in which Messrs Macadam, Cunningham, Bruce Peebles, Blaikie, Procter, and others took part, and the President thereafter reviewed the whole matter, and in name of the Society thanked the Author for the Communication. It was agreed, on the motion of Mr Blaikie, to print an Abstract of the Paper in the *Transactions* of the Society.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

II. Dr Macadam then moved that Law XV. be altered in accordance with the terms printed in the Billet for the meeting, which were as follows:—

"The Society shall hold an Annual General Meeting on the second Monday in November, at Eight o'clock P.M., or on such other day, or

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at such hour, as the Society from time to time shall ordain. The Annual General Meeting shall be open to the public, under such regulations as the Council shall judge proper. At this Meeting the Report of the Prize Committee shall be read, and the President, or in his absence one of the Vice-Presidents, or the Preses of the Meeting, shall present the Prizes to the successful Candidates. Two weeks prior to this meeting the Secretary shall issue a notice to the Fellows, containing a list of names recommended by the Council as Office-Bearers for the ensuing Session, and any Fellow desirous of adding other names to the list of nominations must give one week's clear notice of such to the Secretary, who shall publish all the recommendations in the Billet for the Meeting. At this Meeting the Society shall elect from the list of nominations so made, a President, two Vice-Presidents, twelve Ordinary Councillors, a Secretary, a Treasurer, and an Editor of Transactions. These shall collectively form a Council for the purpose of transacting the private business, regulating the order of public business in accordance with the Laws of the Society, and watching over the general interests of the Society, all of whom may be re-elected except the four Ordinary Councillors at the head of the list, who must retire from that office for at least one year. Four Members of Council shall constitute a quorum."

The motion was seconded by Mr Fraser.

Mr Johnston Stephen moved an amendment that consideration of the matter be postponed, and this was seconded by Dr Taylor, and, on a vote being taken, the amendment was carried.

III. Mr Blaikie then moved that the Society petition the First Lord of the Treasury to continue the Grant allowed to the late Dr Sang to his daughters. The motion was seconded by Mr Bruce Peebles, and agreed to.

IV. The following resignations were intimated and accepted.

Mr Hugh Morton Gavin. Mr William Hume.
Mr William Watson.

Ninth Meeting—23*rd March* 1891.—The Chair was occupied at the opening of the meeting by Mr R. K. Miller, Vice-President, but was afterwards taken by the Right Hon. Lord Kingsburgh, President, supported by both Vice-Presidents.

Mr Louis Rottenburg contributed a paper, which was read by the Secretary, on a Pedal Vice, illustrated by a Diagram and Model. The invention was discussed by Messrs Blaikie, Bruce Peebles, Miller, and Ritchie, and remitted to a Committee consisting of Mr Kirkwood, Mr

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A. D. Mackenzie, and Mr Mather, the latter being Convener, who should report.

Mr Holroyd Smith then contributed a paper on Electric Traction, which was profusely illustrated with Drawings and Diagrams. An animated discussion followed the reading of this paper, in which Messrs Colam, Miller, Ferguson, Bruce Peebles, and Pitcairn took part, after which the President conveyed the thanks of the Society to the Author, and it was agreed to print the paper in the *Transactions*.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

Tenth Meeting—13*th April* 1891.—Mr W. B. Blaikie, Vice-President, occupied the Chair, supported by Mr R. K. Miller, Vice-President.

The Secretary read the Committee's Report on Mr Hume's paper on Domestic Hot Water Apparatus, which was adopted by the Society.

Mr John Whitelaw then submitted a paper on an Improved Mining Theodolite, illustrated by Drawings, and by exhibition of the Instrument.

A discussion followed the reading of the paper, in which Messrs Penman, Cadell, Miller, Kay, and others took part, and thereafter the paper was remitted to a Committee consisting of Mr Charles Stevenson, Mr W. B. Blaikie, and Mr Wm. Penman, the latter being Convener.

Mr J. J. Cadell next submitted a paper on a Clinometric Attachment to the Pocket Sextant. The Chairman, after making some remarks on the ingenuity of the invention, remitted the paper to a Committee, consisting of Mr Charles Stevenson, Mr W. B. Blaikie, and Mr Penman, Convener, for the purpose of reporting thereon.

Mr W. P. Buchan then read his papers on the Smoke Test for Drains, and on the Ventilation of Schools. In the discussion which followed, Messrs Gilmour, Whitelaw, Kay, and Dr Ferguson took part, and thereafter the Chairman conveyed the thanks of the Society to the Author.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

II. Dr Macadam then opened the discussion on his motion for the alteration of Law XV., and concluded by moving its adoption. The motion was seconded by Mr Kay.

Mr Johnston Stephen moved that the words "by the Council," following the words "names recommended," be deleted from the proposed alteration. This was seconded by

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Mr Bruce Peebles. This amendment was afterwards withdrawn.

Mr Johnston Stephen then moved a further amendment to the effect that salaried officers of the Society should not be Members of Council, and should only attend Council meetings when required. This amendment was duly seconded.

Dr Ferguson moved, and Mr Whitelaw seconded, that consideration of the matter be delayed to a future meeting. On the amendments and motion being put to the meeting, Dr Macadam's motion was carried by a majority of two-thirds.

III. The Secretary intimated the resignation of Mr George A. Panton, which was accepted.

Eleventh Meeting—27th April 1891.—The Chair was occupied by Mr W. B. Blaikie, Vice-President, supported by Mr R. K. Miller, Vice-President.

In the absence of the Secretary, Mr Penman read the Report of the Committee on Mr W. Rottenburg's paper on a Pedal Vice, and the Report was adopted by the Society.

Mr W. B. Blaikie then submitted a paper on some Mechanical Appliances for demonstrating Geographical Problems, illustrated by Drawings and Apparatus. The paper was afterwards discussed by Messrs Peebles, Miller, D. Stevenson, and Penman, and the meeting resolved that it should be reported on by a Committee of Messrs F. G. Ogilvy, Dr Ferguson, and Mr D. A. Stevenson, Convener, and also that it should be printed in the *Transactions*.

Mr H. M. Cadell then read a paper on the International System of Water and Sewage Purification, illustrated by various experiments. In the discussion which followed, Dr Macadam and Messrs W. J. Macadam, Kemp, and Miller took part, and the Chairman suggested that it should be published. It was then remitted to the following Committee, viz., Mr Leslie, Mr D. A. Stevenson, and Mr Dyce Cay, Convener, for the purpose of being reported on.

Private Business.

I. The Minutes of the previous meeting were read and confirmed.

II. Dr Stevenson Macadam then moved the adoption of his motion for the alteration of Law XV., and the motion was seconded by Mr Miller. Mr Johnston Stephen moved as an amendment, "that no salaried officer of the Society be

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eligible as a Member of Council," and this was duly seconded. After much discussion it was resolved that the Secretary should print both the motion and the amendment in the Billet for the next meeting, for the consideration of the Society.

Twelfth Meeting—11*th May* 1891.—The Chair was occupied by Mr W. B. Blaikie, Vice-President, supported by Dr Taylor, Councillor.

The Secretary read Reports by Committees on Mr Whitelaw's and Mr Cadell's Papers, and these were adopted by the Society.

Professor A. B. W. Kennedy then read a paper on a Description and Comparison of the Systems of Electric Lighting at present in use in London, illustrated by Diagrams. The paper was listened to with great interest, and in the discussion which followed, Messrs Ferguson, Bruce Peebles, Ogilvy, Johnston, Wilkins, Russel, Taylor, &c. took part. The Chairman then thanked the Author on behalf of the Society, and it was agreed to publish the Communication in the *Transactions*.

Mr Grant Ogilvy invited the Fellows to visit the Heriot-Watt College, where they could inspect the working of the various kinds of machinery described by Professor Kennedy.

Private Business.

The Chairman, at the request of the Society, granted the Treasurer his discharge for his intromissions of last session.

Thirteenth Meeting—25*th May* 1891.—The Chair was occupied by Mr W. B. Blaikie, Vice-President.

The Secretary read the following Reports from Committees:—

1. On Mr Baird's paper on Patent Silent Carriage-Wheels.
2. On Mr Blaikie's paper on Ambulance Appliances.
3. On Dr R. M. Murray's paper on an Electrical Bench.
4. On Dr R. M. Murray's paper on a Galvanometer.

The above Reports were adopted by the Society.

The Report on Mr Gray's paper on Heating and Ventilating Buildings having been read, the Author took exception to several points in the Report, and the Society remitted the matter back to the Committee for further consideration.

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Private Business.

I. The Secretary read the Minute of the Eleventh Meeting of the Society, and a discussion arose as to the accuracy of same. On a vote being taken, a majority held that the Minute was correct, and it was accordingly confirmed. The Secretary then read the Minute of the Twelfth Meeting, which was also confirmed.

II. The Society then proceeded to appoint the Prize Committee for dealing with papers submitted during the Session, and accepted the list of names recommended by the Council, viz.:—

The Right Hon. Lord Kingsburgh, President.
Mr R. K. Miller, Vice-President.

Mr H. J. Blanc.	F. Mather.	Wm. Taylor.
W. D. Cay.	F. Grant Ogilvy.	D. M. Westland.
W. Firth.	Wm. Penman.	
P. L. Henderson.	D. A. Stevenson.	

III. The recommendation of the Council, with regard to the Secretary's salary, was then submitted.

Dr Macadam moved that the Secretary's salary be reduced to thirty guineas, but the motion was not seconded.

Mr Kemp moved that the question of salaries be again remitted to the Council for a Report, and this was seconded by Dr Ferguson. There being no other motion before the Society, Mr Kemp's motion was accepted, and the matter accordingly remitted.

IV. The alteration of Law XV. was then discussed, and Dr Macadam's motion was eventually withdrawn.

V. The Society instructed the Secretary to receive the Reports by Committees not yet lodged, and submit same in due course to the Prize Committee.

VI. The resignations of Messrs Lindsay, Lumsden, and M'Farlane were intimated and accepted.

VI. The Circular from the Secretary of the Seventh International Congress of Hygiene and Demography to be held in London in August was submitted, and the Society remitted to the Secretary to advise any Fellows who might be going to London to attend the Congress.

The Society then adjourned till November.

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LIST OF DONATIONS PRESENTED TO THE SOCIETY DURING THE SESSION 1890-91.

Proceedings of the Royal Society.
" of the Royal Society of Edinburgh.
" of the Royal Institution of Great Britain.
" of the Royal Physical Society.
" of the Royal Irish Academy.
" (Scientific) of the Royal Dublin Society.
" of the Royal Society of Victoria.
" of the Institution of Civil Engineers.
" of the Institution of Mechanical Engineers.
" of the Philosophical Society of Glasgow.
" of the Canadian Institute, Toronto.
" of the Boston Society of Natural History.
" of the American Academy of Arts and Sciences.
Transactions of the Royal Society of Edinburgh.
" of the Royal Irish Academy.
" of the Royal Society of Victoria.
" of the Institution of Engineers and Shipbuilders in Scotland.
" of the Institution of Civil Engineers in Ireland.
" of the Canadian Society of Civil Engineers.
" of the Canadian Institute.
" of the Edinburgh Architectural Association.
Journal of the Society of Arts.
" of the Franklin Institute.
" of the Scottish Meteorological Society.
Engineering.
The English Mechanic.
The Watchmaker, Jeweller, and Silversmith.
The Manufacturer and Inventor Newspaper.
Memoirs and Proceedings of the Manchester Literary and Philosophical Society.
Memoirs of the Geographical Survey of India.
Memoirs (Cunningham), No. 6.—*Presented by the Royal Irish Academy.*
Memoirs of the Boston Society of Natural History.
Records of the Geological Survey of India.
Tenth Report of the Committee of Management of the Technological, Industrial, and Sanitary Museum of New South Wales, 1889.
Laboratory Reports of the Royal College of Physicians, Edinburgh.
The Inventor.
The Manufacturer.
Thirty-fourth Annual Report of the Council of the Manchester Association of Engineers, with discussional paper on the Merits of Driving by Spur or Bevil Gearing Belts or Ropes.
Smithsonian Reports of the United States National Museum.
Patents for Inventions, Abridgments of Specifications, Divisions 1, 2, 3, 4 in 7 Books.

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The Scientific Papers of Professor James Clerk Maxwell, vols. i. and ii. *Presented by the Syndics of the Pitt Press.*
Bulletin of the Minnesota Academy of Natural Sciences.
The Junior Engineering Society, 1890–91.
List of the Members of the Institution of Civil Engineers.
Charter, Bye-Laws, and List of Members of the Canadian Society of Civil Engineers.
Series of Papers read before the Manchester Association of Engineering during the Session 1890.
Decimal Coinage, Weights, and Measures popularly explained.
Ventilation. By William Paton Buchan.—*Presented.*
Atti E Memorie della R Accademia di Scienze Letteri ed Arti in Padova.
Atti della Reale Accademia delle Scienze di Torino.
Annales de l'Association des Ingénieurs de Gand.

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APPENDIX (G).

LIST OF PRIZE SUBJECTS FOR SESSION 1891-92.

THE ROYAL SCOTTISH SOCIETY OF ARTS proposes to award Prizes of different values, of Thirty Sovereigns and under, in Gold or Silver Medals, Silver Plate or Money, for approved Communications, *whether previously published or patented, or not,* submitted to the Society by Fellows or others, relative to Inventions, Discoveries, and Improvements in the *Mechanical* and *Chemical* Arts in general, and in their relation to the Fine Arts, and also to means by which the *Natural Productions* of the Country may be made more available. The Society suggests the following as a few of the many subjects that may be attended to, viz.:—

INVENTIONS, DISCOVERIES, OR IMPROVEMENTS in the Useful Arts.

1. *Mechanical Arts.*

INVENTIONS OR IMPROVEMENTS in applying the Motive Power of Men and Animals,—in Wind and Water Prime Movers,—in Steam and other Heat Engines, including Gas Engines,—in Pumping, Blowing, Rolling, Sawing, Agricultural and other Engines and Machines,—in Cotton and other Textile Manufacturing Mills,—in Shipbuilding in Wood, Iron, and Steel,—in Lighthouses,—in Marine Propellers,—in Railways, Plant, and Signals,—in Electric Apparatus,—in Electro Magnetic Motive-Power,—in Electric and other Telegraphic Apparatus, Sub-Marine and Aërial,—in Photographic Apparatus,—in Fire-Proof Buildings,—in Water Supply,—in Paving,—Sewerage,—in Economical Appliances for

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increasing the Sanitary Condition of Towns,—in Smoke consumption and extinguishing Fires,—in Gas-Works,—in Canals and Inland Navigation, including the application of Steam Power to Canal Traffic,—Canal Locks, Inclines, and Lifts,—Application of Hydraulic Power for Lifts for Domestic Use, for Cranes, Printing Presses, Organ-Blowing, and other similar purposes, where small Propelling Power is required,—Labour-Saving Machines for Working in Wood,—in Tools, Implements, and Apparatus for the various Trades,—in Sewing Machines,—in Brick, Encaustic Tiles, Cements and Mortars,—in Printing Machines, Cases, and Rollers,—in Stereotyping,—in Cranes,—in the Machinery for Collieries,—in Preserving Timber and Metals in Marine Works,—in Optical Apparatus,—in Manufacture of Paper,—Experiments on the Effect of Low Temperatures on Metals.

2. *Chemical Arts.*

INVENTIONS or IMPROVEMENTS in new and useful applications of Gutta Percha and Vulcanised Indiarubber, or similar Gums,—in the Economical Extraction of Chemical Principles or Useful Substances, as Paraffin, &c., from Coal,—Porcelain Clay from Granite or Felspar,—and Metals generally from their Ores and Oxides,—in Dyes,—in Paints,—in Paper,—in Glass, especially for Lenses,—in methods of rendering the Electric Light available in practice.

3. *Relative to the Fine Arts.*

INVENTIONS or IMPROVEMENTS in Photographic Processes, in "Carbon" Printing, and in methods of Printing Photographs from their Impressions on Steel or Copper Plates, or Lithographic Stones,—in Electrotype Processes,—in Die-Sinking,—in methods of illustrating Books, to be printed with the letter-press,—in Paper Hangings,—in Articles of Porcelain, Common Clay or Metal,—in Glass Staining,—in Engraving on Stone,—in Chromo-Lithography,—in "Nature" Printing.

4. *Natural Productions.*

I. DISCOVERY of Plumbago Mines,—Whetstones,—of Woods suitable for Engraving.

II. EXPERIMENTS applicable to the Useful Arts.

III. COMMUNICATIONS of Processes in the Useful Arts practised in this or other Countries, but not generally known.

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IV. PRACTICAL DETAILS of Public or other Undertakings of National importance, already executed, but not previously published;—or valuable suggestions for originating such undertakings.

The KEITH PRIZE, value Thirty Sovereigns.

For some important "Invention, Improvement, or Discovery in the Useful Arts, which shall be primarily submitted to the Society" during the Session.

The HEPBURN BIENNIAL PRIZE, value about £12.

"For such Inventions or Communications submitted to the Society as shall be approved of by the Society, or by their Prize Committee."

The MAKDOUGALL-BRISBANE BIENNIAL PRIZE, value £10.

"To the Authors or Inventors of Communications of Merit, which shall be approved of by the Society, or its Committee, and judged by them deserving of such distinction."

The REID and AULD PRIZES.

For the First, Second, and Third best Models of "Anything New in the Art of Clock or Watch Making,—by Journeymen or Master Watch and Clock Makers,"—if these should be considered worthy of Prizes, the Year's Interest of the Reid and Auld Bequest, being about SEVEN GUINEAS, divided among them in such proportions as the Prize Committee shall fix, according to merit. To such as deserve it, the Society may add to the amount of the Prize out of its general funds.

GENERAL OBSERVATIONS

AND DIRECTIONS FOR PREPARING AND LODGING COMMUNICATIONS.

The descriptions of the various inventions, &c., must be *full* and *distinct;*—be legibly written on *Foolscap* paper, leaving margins at least one inch and a half broad, on *both sides of each page*, so as to allow of their being bound up in volumes; and, when necessary, be accompanied by *Specimens*, *Drawings*, *or Models*. All Drawings to be on *Imperial* Drawing-Paper, unless a larger sheet be

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requisite. The Drawings to be in *bold* lines, not less than a quarter of an inch broad, or *strongly coloured*, so as to be easily seen at about the distance of 30 feet when hung up in the Hall, and the Letters or Figures of Reference to be at least 1½ inch long. When necessary, smaller and more minutely detailed Drawings should accompany the larger ones, for the use of the Committee, having the same letters of reference. Short abstracts must accompany the papers.

The Society shall be at liberty to publish in their *Transactions* copies or abstracts of all papers submitted to them. All Models, Drawings, &c., for which Prizes are given, shall be held to be the property of the Society; but the Value of the Model, if retained, will be separately allowed for.

Communications, Models, &c., are to be addressed to the SECRETARY, 117 George Street, Edinburgh, Postage or Carriage paid. Communications lodged after the 1st March may not be read or reported on till the following Session.

By order of the Society,

WM. ALLAN CARTER,
Secretary.

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APPENDIX (C).

REPORT BY THE COMMITTEE APPOINTED TO AWARD PRIZES FOR COMMUNICATIONS READ OR REPORTED ON DURING THE SESSION 1890–91.

Your COMMITTEE having met and carefully considered the various Communications laid before the Society, or reported on and definitely disposed of by the Society during the Session 1890–91, including those submitted at the Special Meeting held in the International Exhibition on the 13th October 1890, beg to report—

That your Committee have awarded the following Prizes:—

To DR R. MILNE MURRAY,—for his paper 'On an Electrical Bench for Physiological Research' (No. 4624),—read on the 12th January 1891.

A Keith Prize, value Twenty-one Sovereigns.

To JOHN WHITELAW, C.E.,—for his paper 'On an Improved Mining Theodolite' (No. 4634),—read on the 13th April 1891.

A Keith Prize, value Ten Guineas.

To W. B. BLAIKIE,—for his paper 'On a Hospital Table and Ambulance Appliances' (No. 4626),—read on the 26th January 1891.

A Keith Prize, value Five Guineas.

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To Dr Dawson Turner, Edinburgh,—for his paper on 'The Tesla Phenomena of High Potential Electricity,' and Demonstrations (No. 4672),—read on 13th March 1892.

A Keith Prize, value Five Sovereigns.

To Cossar M'Kenzie, Engineer, Edinburgh,—for his paper on 'A Hydraulic Valve for High Pressures' (No. 4673),—read on the 13th March 1893.

A Keith Prize, value Five Sovereigns.

To John Ritchie, Engineer, Edinburgh,—for his papers on 'The Utilisation of Water for Power, and Transmission of Same' (No. 4674),—read on 27th March, and on 'Improved Turbines for the Utilisation of Water Power' (No. 4676),—read on the 10th April 1893.

A Keith Prize, value Five Sovereigns.

And that the best Thanks of the Society are due

To Alexander Leslie, C.E., President, — for his opening Address, delivered on the 14th November 1892.

To Dr Stevenson Macadam,—for his paper on 'Flour and Malt Dust Fire-Explosions' (No. 4661),—read on the 28th of November 1892.

To R. Hedger Wallace,—for his paper on 'Problems in Agricultural Teaching at Home and Abroad' (No. 4663), —read on the 12th December 1892.

To Charles A. Stevenson, C.E.,—for his paper on 'The Mode of Calculating Spherical Refractors' (No. 4664),—read on 12th December 1892.

To William Ivison Macadam,—for his paper on 'The Manufacture of Gas for Illuminating and other purposes' (No. 4665),—read on the 9th January 1893.

To Duncan Bell,—for his paper on 'Aerial Machines' (No. 4666),—read on the 23rd January 1893.

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To WILLIAM BENNETT,—for his paper on 'The British Navy' (No. 4667),—read on the 23rd January and 13th February 1893.

To Dr W. G. BLACK,—for his paper on 'Meteorology at the Sea Side, English Channel, Winter' (No. 4668),—read on the 13th February 1893.

To the REPRESENTATIVES of the late LAURENCE HILL, C.E., Glasgow,—for the paper prepared by Mr Hill on a 'Non-Automatic or Confidence Water Meter' (No. 4671), —read on the 27th February 1893.

To Dr FERGUSON, Edinburgh,—for his paper on 'A Domestic Hot Water Supply' (No. 4675),—read on the 27th March 1893.

And to G. H. GEMMELL,—for his paper on 'Micro-organisms in Drinking Water in relation to Public Health' (No. 4677), read on the 24th of April 1893.

All which is humbly reported in name and by order of the Committee, by

WM. ALLAN CARTER, *Secretary*,
Convener ex officio.

SOCIETY'S HALL, 117 GEORGE STREET,
20th October 1893.

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APPENDIX (O).

Royal Scottish Society of Arts.

ABSTRACT OF THE ACCOUNTS OF THE SOCIETY FOR 1891–92.

I. GENERAL FUND.

CHARGE.

Balance at 15th November 1891—			
Cash in Bank	£38 9 3		
Less—Balance due to the Treasurer	14 3 6		
			£24 5 9
Income—			
Arrears of Subscriptions at 15th November 1891	£9 9 0		
Subscriptions for year 1891–92	168 0 0		
	£177 9 0		
Less—Unpaid at 15th November 1892	8 8 0		
	£169 1 0		
Balance transferred from Building Fund, page 3	70 14 1		
Total Income			239 15 1
Composition Fees			24 3 0
Subscriptions Unpaid at 15th November 1892			8 8 0
			£296 11 10

DISCHARGE.

Ordinary Expenditure—			
Printing and Advertising		£36 9 6	
Salaries and Expenses of Collection	£103 7 6		
Less—Charged to Prize Funds	4 17 0		
		98 10 6	
Interest Paid	£3 8 3		
Less—Interest Received	1 7 9		
		2 0 6	
Expenses connected with the Society's Printed Transactions		55 15 6	
Expenses connected with the Jubilee Dinner, Balance		4 1 0	
Miscellaneous Payments, including Postages		8 13 0	
Total Ordinary Expenditure		£205 10 0	
Subscriptions Irrecoverable		3 3 0	
Do. Outstanding		5 5 0	
Balance at 15th November 1892—			
Sum in Deposit Receipt with the Commercial Bank	£76 7 10		
Balance due by the Treasurer	6 6 0		
		82 13 10	
			£296 11 10

II. KEITH BEQUEST.

CHARGE.

Balance on Deposit Receipt with the Commercial Bank at 15th November 1891			£190 2 7
Income—			
Dividends from Stocks, viz. :—			
Edinburgh and Leith Gas Annuity		£29 5 0	
Great North of Scotland Railway Company Debenture Stock		19 10 0	
Forth and Clyde Junction Railway Preference Stock		4 17 6	
		£53 12 6	
Interest on Loan of £100 to General Fund	£3 8 3		
Interest on Bank Account	3 2 1		
		6 10 4	
			60 2 10
Sum of the Charge			£250 5 5

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II. KEITH FUND.

Charge Amount ..... Forward,			£250 5 5

Discharge.

Expenditure—			
Prizes awarded	£37 3 6		
Commission on Revenue, credited General Fund	3 0 0		
	£40 3 6		
Sum in Deposit Receipt with the Commercial Bank at 15th November 1892	210 1 11		
Sum of the Discharge			£250 5 5

III. REID AND AULD BEQUEST.

Charge.

Balance on Deposit Receipt with the Commercial Bank at 15th November 1891			£116 17 9
Income—			
Interest on Great North of Scotland Railway Company Debenture Stock	£17 11 0		
On Forth and Clyde Junction Railway Preference Stock	2 8 8		
On Bank Account	1 18 2		
		21 17 10	
Sum of the Charge			£138 15 7

Discharge.

Expenditure—			
Donations to poor Clockmakers in terms of the Bequest	£2 0 0		
Prize awarded	3 4 8		
Commission on Revenne, credited General Fund	1 1 0		
	£6 5 8		
Sum in Deposit Receipt with the Commercial Bank at 15th November 1892	132 9 11		
Sum of the Discharge			£138 15 7

IV. BRISBANE BIENNIAL PRIZE FUND.

Charge.

Balance on Deposit Receipt with the Commercial Bank at 15th November 1891			£23 18 3
Income—			
Interest on Forth and Clyde Junction Railway Preference Stock	£7 6 4		
On Bank Account	0 7 8		
		7 14 0	
			£31 12 3

Discharge.

Expenditure—			
Prizes awarded	£3 10 4		
Commission on Revenue, credited General Fund	0 8 0		
	£3 18 4		
Sum in Deposit Receipt with the Commercial Bank at 15th November 1892	27 13 11		
Sum of the Discharge			£31 12 3

V. HEPBURN PRIZE FUND.

Charge.

Balance on Deposit Receipt with the Commercial Bank at 15th November 1891			£46 19 1
Income—			
Dividends on Caledonian Railway Company Stocks	£7 5 1		
Interest on Bank Account	0 15 3		
		8 0 4	
Sum of the Charge			£54 19 5

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V. HEPBURN PRIZE FUND.

Charge Amount.....Forward,		£54 19 5

DISCHARGE.

Expenditure—		
Prizes awarded	£3 10 0	
Commission on Revenue, credited General Fund	0 8 0	
	£3 18 0	
Sum in Deposit Receipt with the Commercial Bank at 15th November 1892	51 1 5	
Sum of the Discharge		£54 19 5

VI. BUILDING FUND.

CHARGE.

Rents drawn from Letting the Hall	£243 2 7

DISCHARGE.

Payments on Account of the Hall, viz., Taxes, Feu-duty, Insurance, Coals, Gas, Cleaning, &c., and Hallkeepers, Salary	£126 15 6	
Repairs to the Hall	45 13 0	
		172 8 6
Balance transferred to the General Fund, page 1		£70 14 1

FUNDS OF THE SOCIETY,

As at 15th November 1892, *per Report of the Auditor.*

I. GENERAL FUND.

Price of Hall in George Street and Furnishings, and of the additional Premises purchased at Whitsunday 1863	£2712 0 3
Balance due by Commercial Bank on Deposit Receipt	76 7 10
Balance due by the Treasurer	6 6 0
Arrears of Annual Contributions	5 5 0
	£2799 19 1
Less—Loan from Keith Fund	100 0 6
Amount of General Fund	£2699 19 7

II. KEITH BEQUEST.

£30 Annuity of the Edinburgh and Leith Gas Commission	£870 0 0	
Sum lent to the General Fund	100 0 0	
£500 Great North of Scotland Railway Company Debenture Stock	612 10 0	
£100 Preference Stock No. 1 of the Forth and Clyde Junction Railway Company	137 0 0	
Sum in Deposit Receipt by the Commercial Bank	210 1 11	
		1929 11 11
Carry forward,		£4629 11 4

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II. FUNDS OF THE SOCIETY—continued.

Brought forward,			£4629 11 0
III. REID AND AULD BEQUEST.			
£150 Great North of Scotland Railway Company Debenture Stock	£551 5 0		
£50 Preference Stock No. 1 of the Forth and Clyde Junction Railway Company	68 10 0		
Sum in Deposit Receipt by the Commercial Bank	132 9 11		
		752	4 11
IV. BRISBANE PRIZE FUND.			
£150 Preference Stock No. 1 of the Forth and Clyde Junction Railway Company	£205 10 0		
Sum in Deposit Receipt by the Commercial Bank	27 13 11		
		233	3 11
V. HEPBURN PRIZE FUND.			
£175 Caledonian Railway Company Consolidated 4 per cent. Stock, No. 2	£209 2 6		
£11 do., No. 1	13 6 0		
Sum in Deposit Receipt by the Commercial Bank	51 1 5		
		273	9 11
Total Property and Funds under charge of the Society as at 15th November 1892		£5888	9 9

SCOTT-MONCRIEFF, THOMSON & SHIELLS, *for the Treasurer.*

EDINBURGH, 14*th February* 1893.—I have examined and audited the Accounts of the Treasurer to the Royal Scottish Society of Arts, for the Session 1891–92, of which the foregoing is an Abstract, and beg to report that I have found the same to be correctly stated and sufficiently vouched and instructed.

GEORGE H. CARPHIN, C.A., *Auditor.*

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APPENDIX (P).

LIST

OF THE

OFFICE-BEARERS AND FELLOWS

OF THE

ROYAL SCOTTISH SOCIETY OF ARTS.

THE QUEEN, PATRONESS.

HONORARY FELLOWS.

H.R.H. The Prince of Wales.
H.R.H. The Duke of Edinburgh.

OFFICE-BEARERS FOR SESSION 1893-94.

President	William Taylor, M.D., 12 Melville Street.
Vice-Presidents	R. Milne Murray, M.A., M.B., M.R.C.P., 10 Hope Street. F. J. Ritchie, Clockmaker, 25 Leith Street.
Secretary	William Allan Carter, M. Inst. C.E., 117 George Street.
Treasurer	Scott-Moncrieff, Thomson, & Shiells, C.A., 141 George Street.
Editor of Transactions	Stevenson Macadam, Ph.D., F.R.S.E., Surgeons' Hall.
Medalists	Alexander Kirkwood & Son, 9 St James Sq.
Officer	James Stevens, 117 George Street.

Councillors.

D. A. Scott, S.S.C., 20 St Andrew Square.
Charles Ritchie, S.S.C., 20 Hill Street.
John Whitelaw, Civil and Mining Engineer, 118 George Street.
John S. Bayne, Bookseller, 44 Leven Street.
William Galt Black, F.R.M.S., 2 George Square.
Thomas Hume, Plumber, 2A Stafford Street.
A. D. Mackenzie, Engineer, 6 Hartington Gardens.
William Penman, Assoc. M.Inst. C.E., 5 St Andrew Square.
Peter Boa, Chemist, 119 George Street.
Alexander Gray, 4 Royal Terrace.
James MacDonald, Plumber, 3 Dundas Street.
Peter Stevenson, Instrument Maker, 80 Marchmont Crescent.

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LIST OF THE ORDINARY FELLOWS

AS AT 15TH NOVEMBER 1893.

*Those marked * are Life Fellows.*

NOTE.—Fellows may become "Life Fellows" at any time on paying £10, 10s., from which they are allowed a deduction of half the amount they may have paid previously in Annual Contributions.

1863 *Aitchieson, Thos. Stodart, 85 South Back of Canongate
1865 *Aitken, Henry, manager, Darroch Coal and Iron Works, Falkirk
1871 *Aitken, John, F.R.S.E., Darroch, Falkirk
1884 Aitken, John Edington, chemist, 121 Newbigging, Musselburgh
1851 *Alexander, William, M.E.
1841 *Anderson, Charles W., merchant, Dundurn, Trinity Road
1893 Anderson, Robert, 15 Henderson Terrace
1868 *Archibald, John, M.D., Woodhouse Eaves, Loughborough
1892 Argyll, His Grace The Duke of, Argyll Lodge, Kensington
1889 Armstrong, G. F., Regius Professor of Engineering, Edinburgh University
1891 Ayling, John, 6 Hillside Crescent

1889 Bainbridge, A. F., 18 Clyde Street
1889 *Bartlett, William E., North British Rubber Co.
1878 Barton, John Fraser, plumber, 11 Forrest Road
1881 Bayne, John S., bookseller 44 Leven Street, *Councillor*
1889 Beare, T. Hudson, Professor of Engineering, University College London
1871 *Beatson, William, burgh surveyor, Town Hall, Leith
1861 *Beith, Donald, W.S., 43 Castle Street
1850 *Bell, Alexander Melville, Washington
1859 *Bell, Andrew Beatson, advocate, Chairman H.M. Prison Commissioners, Scotland, 143 Princes Street
1889 Bell, Duncan, 42 Frederick Street
1891 Bell, J. Dalrymple, Clifton Hall, Ratho
1867 *Bell, Robert, coal merchant, Clifton Hall, Ratho

1887 Bennett, William, superintendent City Poorhouse, Craiglockhart
1879 Black, William Galt, F.R.M.S., 2 George Square, *Councillor*
1879 Blackwood, John, inspector of lighting, 46 Victoria Street
1883 Blaikie, Walter Biggar, printer, 11 Thistle Street
1879 Blanc, Hippolyte Jean, architect, 73 George Street
1877 *Blyth, James, F.R.S.E., Professor of Mathematics and Natural Philosophy, Andersonian University, Glasgow
1888 Boa, Peter, pharmaceutical chemist, 119 George Street, *Councillor*
1892 Bonar, Horatius, W.S., 15 Strathearn Place
1853 *Bow, Robert Henry, C.E., F.R.S.E., 7 South Gray Street
1863 *Bowie, Andrew F., 16 Duncan Street
1868 *Boyd, James L., S.S.C., Glendouglie, Glenfarg
1892 Breadalbane, The Most Hon. The Marquis of, Harcourt House, Cavendish Square, London
1890 Brebner, R. C., 5 Morningside Drive
1889 Brewis, John, C.A , 5 North St David Street
1892 Brier, Henry, engineer,
1864 *Brown, Geo. Bruce, architect, 34 South Hanover Street
1891 Brown, Wm. S., cabinetmaker, 65 George Street
1891 Browning, Ernest Albert, 122 George Street
1880 *Bruce, A. Fairlie, C.E.
1868 *Bruce, C., banker, 3 Melville Crescent
1850 *Bruce, George Cadell, C.E.
1857 *Bryson, J. M., optician, 60 Princes Street
1890 Bryson, W. A., 11 Bothwell Street, Glasgow

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1893 Buchan, Mathew, electrician, 20 Bath Street, Portobello
1879 *Buchan, William Paton, sanitary engineer, 21 Renfrew St., Glasgow
1893 Buchanan, James, Oswald Road
1879 Buchanan, John, C.E., 24 George St.

1891 Cadell, Henry Moubray, of Grange, Bo'ness
1889 Cadell, James J., Carron Park, Larbert
1846 *Callender, John A., merchant, India Buildings
1890 Capper, S. H., M.A., architect, 1 Beaufort Road
1891 Carey, William, colliery manager, Bridgeness, Bo'ness
1879 Carfrae, George, C.E., 1 Erskine Place
1872 *Carment, John, LL.D., S.S.C., 36 Great King Street
1880 Carmichael, Neil, M.D., 23 Nithsdale Road, Pollockshields, Glasgow
1892 *Carphin, G. H., C.A., 24 Northumberland Street
1858 *Carphin, James R., C.A., chamberlain to the Merchant Company, 24 Northumberland Street
1840 *Carstairs, Drysdale, merchant, Hailes House, Fairfield, Liverpool
1875 Carter, William Allan, M. Inst. C.E., 5 St Andrew Square, *Secretary*
1891 Cashmore, Charles, manufacturer, Hastings Street, Loughborough
1872 *Cattanach, Peter Lorimer, advocate, 14 London Street
1867 *Cay, William Dyce, M. Inst. C.E., 107A Princes Street
1860 *Charnock, Richard Stephen, 30 Millman Street, Bedford Row, London
1861 *Chisholm, David, actuary, 9 Rill Bank Terrace
1892 Chisholm, John C., solicitor, 10 St Andrew Square
1856 *Chisholm, John Knox, dentist, 15 Duke Street
1860 *Christie, John, 19 Buckingham Terrace
1866 *Clapperton, W. R., merchant, 59 Princes Street
1879 Clark, Alexander, C.E., Ubeda, Townsend Crescent, Kirkcaldy
1889 Clark, Thomas B., C.A., 64 Queen Street
1878 Clement, Adam Ferguson, telegraph engineer, 8 Ethel Terrace
1889 Colam, William N., C.E., Billiter Buildings, London (E.C.)
1882 Coldstream, John Philips, W.S., 6 Buckingham Terrace
1880 Colville, Arthur, builder, 20 Mayfield Road
1882 Cooper, John, burgh engineer, 1 Parliament Square
1862 *Copland, Harry Y. D., 21 Manor Pl.
1876 Cormack, D. Adair, marine engineer, 3 Sandford Street, Portobello
1872 *Couper, Charles Tennant, advocate, 3 Charlotte Square
1888 Cowan, John, 6 Salisbury Road
1873 *Cox, Robert, 34 Drumsheugh Gardens
1872 *Coyne, Roderick A. F. A., C.E., 11 Royal Exchange
1883 Crabbie, George, merchant, 56 Palmerston Place
1885 Cran, John, mechanical engineer, Albert Engine Works, Leith
1876 *Cranston, Robert, 47 North Bridge
1891 Cruickshank, John, Assessor of Fire Losses, 73 George Street
1851 *Cunningham, George Miller, C.E., 3 Ainslie Place
1879 Cunningham, James H., C.E., 4 Magdala Crescent
1863 *Currie, Heriot, engineer, 17 North Fort Street, Leith
1890 Cushney, John, electrical engineer, (No address)

1892 Davidson, John, watchmaker, Wick
1867 *Deans, Peter Dods, 62 Great King Street
1865 *Deas, James, C.E., Clyde Trust, Glasgow
1850 *Dickson, John, gunmaker, 63 Princes Street
1882 Dickson, Lamont, C.E., 135 George Street
1890 Dobbie, John, quarrymaster, 13 East Hermitage Place, Leith
1882 Dobie, Geo., painter, 9 Priestfield Road
1891 Donaldson, James, gas engineer, Gasworks, Cambuslang
1892 Douglas, William, telephone engineer, 63 York Place
1892 Douglass, J. R., C.E., 32 Blacket Place
1892 Douglass, W.L., C.E., 32 Blacket Place
1891 Dow, William B., F.R.C.S.E., Dunfermline
1887 Drysdale, Alexander, builder, 8 Dalmeny Street
1893 *Duncan, D. J. Russell, Kilmarnock, Lee
1890 Dunn, James B., architect, 94 George Street
1866 *Dunn, John H., 13 Glengyle Terrace

1892 Elgin and Kincardine, The Right Hon. The Earl of, Broomhall, Dunfermline

1878 Farquharson, Thomas Kerr, accountant, 100 Thirlstane Road

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1864 *Ferguson, John, engraver, 15 Brighton Place, Portobello
1857 *Ferguson, R. M., LL.D., Ph.D., F.R.S.E., 5 Learmonth Terrace
1860 *Firth, William, secy., N. B. Rubber Co., Wideford, Granton Road
1891 Foggie, John, University College, Dundee
1850 *Fraser, Alexander, printer, Canonmills Lodge
1879 Frazer, Alexander, M.A., optician, 22 Teviot Place

1893 Gardner, C. M., A.I.E.E., 122 George Street
1856 *Geddes, A. C., C.E., 16 Athole Crescent
1856 *Geddes, G. H., M.E., 8 Douglas Crescent
1889 Gibson, J. D., ordained surveyor, 63 George Street
1842 *Gillespie, Sir John, W.S., 53 Northumberland Street
1887 Gilmour, George, builder, 34 Rosslyn Crescent
1871 *Glover, Thomas Craigie, C.E., 29 Hope Terrace, Grange
1859 *Gordon, Alexander, 34 Melville Street
1851 *Gordon, James Newall, London
1861 *Gowans, A., 14 Blantyre Terrace
1865 *Gray, Alexander, 4 Royal Terrace, *Councillor*
1860 *Gray, Rev. W. H., M.A., D.D., minister of Liberton
1889 Gray, William, 52 Frederick Street
1858 *Greig, David, engineer, Greenhill Park
1893 *Grieve, George K., 12 Cambridge Avenue
1889 Grieve, Nathaniel, builder, 15 Ardmillan Terrace

1860 *Hardie, Walter, printer, 77 Rose Street
1888 *Harris, William A., F.S.S., F.I. Inst., secretary Phœnix Fire Office, Exchange, Liverpool
1870 *Hartnell, Wilson, engineer, Park Row, Leeds
1853 *Hay, Geo. W., of Whiterigs, F.R.S.E., Devon Lodge, Starcross, Devon
1879 Heath, Thomas, assistant observer, Royal Observatory
1888 Henderson, George, architect, 12 Queen Street
1890 Henderson, Peter L., architect, 122 George Street
1856 *Henry, Alex., gunmaker, 12 South St Andrew Street
1891 Herdman, G. W., B.Sc., St Bernards, Bruntsfield Crescent
1890 Heron, Charles Miller, 64 Frederick Street
1891 Heron, David, builder, 84 Albert Street, Leith Walk
1888 Hill, William Scott, 47 Manor Place
1871 *Hislop, George Robertson, F.C.S., gas engineer, Blackstone Road, Paisley
1863 *Hogue, D. W., M.D., dentist, 8 Glencairn Crescent
1864 *Hood, Archibald, M.E., Rosewell
1887 Hopper, Frederick G.,
1868 *Horsburgh, John, photographer, 131 Princes Street
1893 Horsburgh, J. Alfred, photographer, 131 Princes Street
1892 Howkins, John, C.E., Granton
1888 Hume, Thomas, plumber, 2A Stafford Street, *Councillor*
1876 *Hutchison, James T., 12 Douglas Crescent
1893 Hunter, H. W., Catherine Street Court

1882 *Inglis, John William, F.R.S.E., M. Inst. C.E., 19 Montpelier, Edinburgh
1891 Irvine, Robert, F.C.S., F.R.S.E., Royston, Granton

1884 Jackson, William, coach builder, 70 Fountainbridge
1885 James, Alexander, M.D., F.R.C.P.E.,
1893 Jamieson, John, 4 Marchhall Crescent
1884 Jenkinson, Alexander Dixson, glass manufacturer, 10 Princes Street
1867 *Johnstone, James, of Larch Hill, 8 Merchiston Park
1850 *Jopp, Charles, C.E., 15 Eglinton Crescent

1872 *Kemp, D. William, Ivy Lodge, Trinity
1890 Kerr, Henry F., architect, 36 Hanover Street
1872 *Key, William, 5 Eildon Villas, Mount Florida, Glasgow
1873 *Kirkwood, Alex., 9 St James Square, *Medalist*
1884 Knott, George brewer, 15 Merchiston Park
1887 Knox, Patrick plumber, 31 Crichton Place

1884 Laidlaw, Robert, engineer, 147 East Milton Street, Glasgow
1893 Laing, John, F.I.C., M.S.A. Lond., 3 Mentone Terrace
1861 *L'Amy, Sylvester (No address)
1857 *Landale, Andrew, ironmaster, Comely Bank Place, Dunfermline

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1852 *Landale, David, M.E., 10 St Andrew Square
1856 *Lees, William, A.M., 12 Morningside Place
1892 Leighton, John T., 20 Picardy Place
1866 *Leslie, Alexander, C.E., M.Inst. C.E. 72 George Street
1873 *Lewis, David, Roselea Villa, Grange
1888 Lindsay, James, The Firs, 10 Craigmillar Park
1877 *Lockie, John, engineer, 2 Commercial Street, Leith
1879 Lyon, William, 8 Randolph Cliff

1856 *Macadam, Stevenson, Ph.D., F.R.S.E., Surgeons' Hall, *Editor of Transactions*
1877 *Macadam, W. Ivison, F.C.S., F.R.S.E., Lecturer on Chemistry, Surgeons' Hall
1839 *Macbriar, David J., S.S.C., 8 Hailes Street, Gilmore Place
1879 M'Cudden, Edmund, C.E., India
1882 Macdonald, James, plumber, 3 Dundas Street, *Councillor*
1889 *Macdonald, The Right Hon. J. H. A., Lord Justice-Clerk of Scotland, 15 Abercromby Place
1887 M'Kean, John, photographer, 1 Ferry Road, Leith
1888 Mackenzie, A. Donald, heating engineer, 6 Hartington Gardens, *Councillor*
1888 Mackenzie, Cossar, ironfounder, 3 Westhall Gardens
1839 *Maclagan, Sir Douglas, M.D., F.R.S.E., Professor of Medical Jurisprudence, 28 Heriot Row
1863 *Maclagan, Peter, of Pumpherston, M.P., Mid-Calder
1867 *Maclagan, R. Craig, M.D., 5 Coates Crescent
1872 *M'Neill, John, plumber, 6 Mill Street, Perth
1890 M'Neill, Peter, cabinetmaker, 22 Howe Street
1863 *Macnie, John, gas engineer, Lecky Road, Londonderry
886 M'Crae, John, gas engineer, Dundee
1858 *Marshall, Thomas R., goldsmith, East Castle Road, Merchiston
1886 Martin, William James, C.E., Rosario de Santa Fé, S. America
1884 Massie, James, engineer, 1 Parliament Square
1876 Mather, Edward, The Lee, Colinton Road
1880 Matheson, John Sellar, chronometer maker, Shore, Leith
1881 *Maxwell-Müller, R. W., C.E.
1860 *Melville, F. Suther, depute-clerk of Session, 5 West Castle Road, Merchiston
1863 *Menzies, Duncan, C.E., 39 York Place
1865 *Menzies, Wm. John, W.S., Canaan Cottage, Grange Loan
1858 *Mercer, James Tod, advocate
1868 *Miller, Richard Kerr, 13 Lennox St.
1890 Miller, Robert, Lord Dean of Guild, 38 Lauder Road, Edinburgh
1879 Milne, James, Baberton House, Juniper Green
1848 *Milne, John Kolbe, dressing-case maker, 126 Princes Street
1888 Mitchell, James D., Heriothill
1879 Mitchell, Robert, gas engineer, Gas Works, Edinburgh
1889 *Moncrieff, D. Scott, W.S., 17 Duke Street
1892 Monteith, K.M., C.E., The Brunt, Crieff
1863 *More, James L., 4 Danube Street
1872 *Morrison, James, City of Glasgow Improvement Trust, 98 Sauchiehall Street, Glasgow
1890 Morton, W. Scott, decorative architect, Tynecastle
1889 Moxon, Charles, 77 George Street
1857 *Muir, John, brewer, 28 N. Back of Canongate
1866 *Muir, W. J. Cockburn, C.E.
1861 *Muirhead, Andrew, painter, 14 Castle Street
1868 *Murray, John, 48 Castle Street
1884 Murray, Robert M., M.A., M.B., M.R.C.P., 10 Hope Street, *Vice-President*

1874 *Noble, William, millwright, 27 Rosebank Cottages

1889 Ogilvie, F. Grant, Principal, Heriot-Watt College, 27 Blacket Place
1866 *Oliver, John S., merchant, 12 Greenhill Park

1865 *Park, Ebenezer, engineer, 18 Greenside Lane
1863 *Park, James Dove, engineer, 18 Greenside Lane
1885 Paterson, Oscar, glass stainer, 115 West Regent Street, Glasgow
1889 Paterson, Robert H., architect, 10a George Street
1861 *Peebles, D. B., engineer, Tay House, Bonnington
1887 Penman, William, Ass. M. Inst. C.E., 5 St Andrew Square, *Councillor*

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1862 *Pilkington, F. T., architect, 8 Russel Square, London
1882 Pirie, James, C.E., 135 George Street
1889 Pitcairn, John E., 20 Scotland Street
1893 Popplewell, W. C., B.Sc., Edinburgh University
1889 Potts, Henry P., 23 Frederick Street
1878 Proctor, Thomas Rodger, 21 West Maitland Street
1864 *Proudfoot, David C., City Road Trust, 10 City Chambers
1893 Purvis, David, 3 Nile Grove

1857 *Reid, A., optician, 31 Castle Street
1879 Reid, Robert Carstairs, M. Inst. C.E., 72A George Street
1890 *Richard, John Miller, 20 Grosvenor Crescent
1853 *Ritchie, Andrew, watchmaker, 25 Leith Street
1890 *Ritchie, Charles, S.S.C., 20 Hill Street, *Councillor*
1867 *Ritchie, David, smith, 31 Blacket Place
1865 *Ritchie, Frederick James, clockmaker, 25 Leith Street, *Vice-President*
1866 *Ritchie, Jas., M.R.C.S., M.B., C.M., 14 Charlotte Square
1879 Ritchie, John, C.E., 36 Hillside Crescent
1859 *Robertson, G., F.R.S.E., Athenæum Club, Pall Mall, London
1889 Robertson, Robert A., S.S.C., 18 Queen Street
1857 *Rollo, Right Hon. Lord, Duncrub House, Bridge of Earn
1853 *Rose, J. T., shipbuilder
1875 Russell, Right Hon. J. A., M.A., M.B., F.R.S.E., Lord Provost of Edinburgh, Woodville, Canaan Lane

1867 *Sanderson, William, rectifier, Talbot House, Ferry Road
1890 Saunders, Thos. L., Hazleton Villa, Barrhead
1878 Scott, David A., S.S.C., 20 St Andrew Square, *Councillor*
1891 Shanks, John, jun., Tubal Works, Barrhead
1891 Shanks, William, Eastfield, Barrhead
1862 *Shedden, Thomas, M.A., 47 West Cromwell Road, London
1883 Shiells, Henry Kenward, C.A., 141 George Street
1889 Simon, Frank W., architect, 36 Hanover Street
1864 *Simpson, James, architect, Daisy Bank, Ferry Road
1856 *Slight, G. H., Lindisfarne, 265 Romford Road, London, E.
1877 Smith, J. Turnbull, C.A., 5 Belgrave Place
1855 *Smyth, Chas. Piazzi, F.R.SS. L. & E., Clova, Ripon
1877 Sprague, Thomas Bond, M.A., LL.D., F.R.S.E., 29 Buckingham Terrace
1889 Stanfield, Richard, Professor of Engineering, Heriot-Watt College
1850 *Stark, James, M.D., F.R.C.P., F.R.S.E., Underwood, Bridge of Allan
1885 Stephen, Johnston, electrician, Ravelston Cottage, Blackhall, Mid-Lothian
1879 *Steuart, Robert Bromfield, C.E., Bayview Cottage, Saltcoats
1881 *Stevenson, Charles Alexander, B.Sc. Edin., 28 Douglas Crescent
1879 *Stevenson, David Alan, C.E., B.Sc. Edin., F.R.S.E., 84 George Street
1884 *Stevenson, Peter, instrument maker, 80 Marchmont Crescent, *Councillor*
1863 *Stewart, A. Duncan, M. Inst. C.E., 89 Philbeach Gardens, London, S.W.
1850 *Stewart, James W., C.E., 39 York Place
1857 *Sturrock, John, Montebello, Joppa
1846 *Swan, Prof. Wm., LL.D., F.R.S.E., Ardchapel, Helensburgh

1876 *Taylor, William, M.D., 12 Melville Street, *President*
1851 *Tennant, Sir Charles, Bart., St Rollox, Glasgow
1860 *Thomson, Alex., teacher, 5A George Square
1860 *Thomson, Charles William Wodrow, C.A., 16 Lennox Street
1883 Thomson, Gilbert, C.E., 75 Bath Street, Glasgow
1878 Thorburn, William, builder, 86 Buccleuch Street
1861 *Tod, James, engraver, 16 Royal Terrace
1892 Turner, Dawson, M.D., 7 George Square

1880 Umpherston, William, engineer, 13 Claremont Crescent

1882 Waldie, David, coal merchant, 25 Douglas Crescent
1890 Walker, James, surveyor, 30 South Frederick Street
1893 Walker, O. Cox, electrician, 9 West Register Street
1892 Walmsley, R. M., Professor, Heriot Watt College

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1856 *Waterston, George, jun., stationer, 56 North Hanover Street
1890 Waterston, James H., insurance manager, 9 North St David Street
1866 *Watherston, James, builder, Pentland Villa, West Coates
1866 *Watherston, William, builder, 17 Rothesay Place
1892 *Watson, James, M. Inst. C.E., Town Hall, Bradford
1892 Wemyss and March, The Right Hon. The Earl of, Gosford House
1879 Westland, David Monro, M. Inst. C.E., 135A George Street
1861 *Whimster, T., gas engineer, Perth
1879 White, John, C.E., 45 E. Claremont Street
1867 *Whitehead, John, S.S.C., 8 Inverleith Row
1881 Whitelaw, John, civil and mining engineer, 118 George Street, *Councillor*
1884 Whyte, Peter, M. Inst. C.E., superintendent, Leith Docks, 3 Clifton Terrace, Edinburgh
1877 *Wilkins, Samuel B., master of fire-engines, High Street
1859 *Wyllie, James S., 21 Barnton Terrace

1890 Yooll, W. Graham, oil refiner, Cambridge Gardens, Leith
1893 Young, John, C.E., 1 Parliament Square
1893 Young, Robert, 39 Leamington Terrace
1885 Young, William A., engineer, Millburn House, Renfrew
1861 *Younger, Robert, brewer, Croft-an-Righ

TOTAL ORDINARY FELLOWS, 316.

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